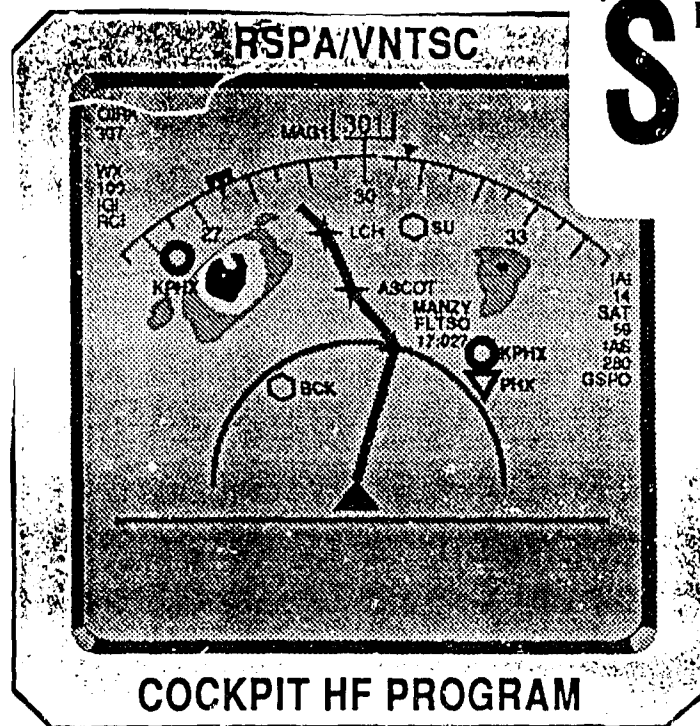


Human Factors Design Principles for Instrument Approach Procedure Charts

Volume I - Readability

AD-A257 234



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for

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Best Available Copy

Final Report
August 1992

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY (Leave blank)

2. REPORT DATE
August 1992

3. REPORT TYPE AND DATES COVERED
Final Report

4. TITLE AND SUBTITLE
Human Factors Design Principles for Instrument Approach
Procedure Charts
Volume I - Readability

5. FUNDING NUMBERS
A1070/FA1EZ

6. AUTHOR(S)
Susan J. Mangold, Donald Eldredge, Erick Lauber

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Battelle
505 King Avenue
Columbus, OH 43201

8. PERFORMING ORGANIZATION
REPORT NUMBER
DOT-VNTSC-FAA-92-9

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Department of Transportation
Federal Aviation Administration
Research and Development Service
Washington, DC 20591

10. SPONSORING/MONITORING
AGENCY REPORT NUMBER
DOT/FAA-RD-92/16,1

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT

This document is available to the public through the National
Technical Information Service, Springfield, VA 22161

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

This Handbook is the first of a series of handbooks which address the issue of Instrument Approach Procedure (IAP) chart improvement in design. The intent is twofold: to review relevant literature that might be applicable to improving the presentation of chart information to support effective and efficient access to information by the user and to develop guidance information based upon this research, that can be easily accessed and implemented by the chart designer. The handbook is intended to offer the chart designer guidance information that can aid in developing charts which clearly present a meaningful visual structure.

14. SUBJECT TERMS

Display Design Principles, Human Factors, Chart Design, Maps, Electronic Displays, Cockpit Displays

15. NUMBER OF PAGES
160

16. PRICE CODE

17. SECURITY CLASSIFICATION
OF REPORT
Unclassified

18. SECURITY CLASSIFICATION
OF THIS PAGE
Unclassified

19. SECURITY CLASSIFICATION
OF ABSTRACT
Unclassified

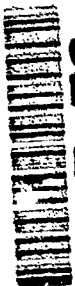
20. LIMITATION OF ABSTRACT

PREFACE

This Handbook is the first of a series of handbooks which address the issue of Instrument Approach Procedure (IAP) chart improvement in design. The intent is twofold: to review relevant literature that might be applicable to improving the presentation of chart information to support effective and efficient access to information by the user and to develop guidance information based upon this research, that can be easily accessed and implemented by the chart designer. The handbook is intended to offer the chart designer guidance information that can aid in developing charts which clearly present a meaningful visual structure.



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METRIC/ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC

LENGTH (APPROXIMATE)

1 inch (in.)	= 2.5 centimeters (cm)
1 foot (ft)	= 30 centimeters (cm)
1 yard (yd)	= 0.9 meter (m)
1 mile (mi)	= 1.6 kilometers (km)

AREA (APPROXIMATE)

1 square inch (sq in, in ²)	= 6.5 square centimeters (cm ²)
1 square foot (sq ft, ft ²)	= 0.09 square meter (m ²)
1 square yard (sq yd, yd ²)	= 0.8 square meter (m ²)
1 square mile (sq mi, mi ²)	= 2.6 square kilometers (km ²)
1 acre	= 0.4 hectares (he) = 4,000 square meters (m ²)

MASS - WEIGHT (APPROXIMATE)

1 ounce (oz)	= 28 grams (gr)
1 pound (lb)	= .45 kilogram (kg)
1 short ton	= 2,000 pounds (lb) = 0.9 tonne (t)

VOLUME (APPROXIMATE)

1 teaspoon (tsp)	= 5 milliliters (ml)
1 tablespoon (tbsp)	= 15 milliliters (ml)
1 fluid ounce (fl oz)	= 30 milliliters (ml)
1 cup (c)	= 0.24 liter (l)
1 pint (pt)	= 0.47 liter (l)
1 quart (qt)	= 0.96 liter (l)
1 gallon (gal)	= 3.8 liters (l)
1 cubic foot (cu ft, ft ³)	= 0.03 cubic meter (m ³)
1 cubic yard (cu yd, yd ³)	= 0.76 cubic meter (m ³)

TEMPERATURE (EXACT)

$$[(x - 32) \div 1.8] = y^{\circ}\text{C}$$

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

1 millimeter (mm)	= 0.04 inch (in)
1 centimeter (cm)	= 0.4 inch (in)
1 meter (m)	= 3.3 feet (ft)
1 meter (m)	= 1.1 yards (yd)
1 kilometer (km)	= 0.6 mile (mi)

AREA (APPROXIMATE)

1 square centimeter (cm ²)	= 0.16 square inch (sq in, in ²)
1 square meter (m ²)	= 1.2 square yards (sq yd, yd ²)
1 square kilometer (km ²)	= 0.4 square mile (sq mi, mi ²)
1 hectare (he)	= 10,000 square meters (m ²) = 2.5 acres

MASS - WEIGHT (APPROXIMATE)

1 gram (gr)	= 0.036 ounce (oz)
1 kilogram (kg)	= 2.2 pounds (lb)
1 tonne (t)	= 1,000 kilograms (kg) = 1.1 short tons

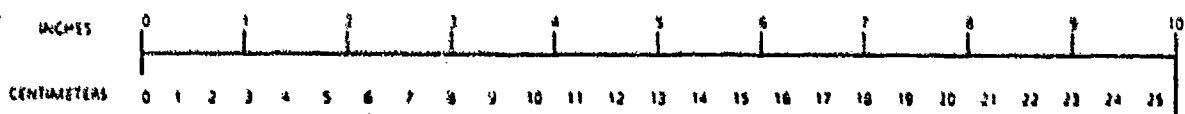
VOLUME (APPROXIMATE)

1 milliliter (ml)	= 0.03 fluid ounce (fl oz)
1 liter (l)	= 2.1 pints (pt)
1 liter (l)	= 1.06 quarts (qt)
1 liter (l)	= 0.26 gallons (gal)
1 cubic meter (m ³)	= 36 cubic feet (cu ft, ft ³)
1 cubic meter (m ³)	= 1.3 cubic yards (cu yd, yd ³)

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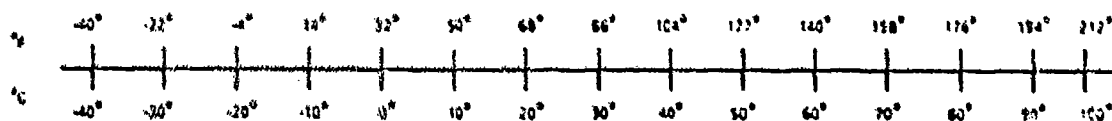
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TABLE OF CONTENTS

<u>Section</u>	<u>Page</u>
1. INTRODUCTION	1
1.1 Objectives and Structure of the Handbook	1
1.2 Caveats	3
2. DISPLAY IMAGE QUALITY	5
2.1 Overview of Chapter 2	5
2.2 The User, The Display Medium, and the Environment	8
2.2.1 Visual System Considerations	8
2.2.1.1 Spatial Vision	9
2.2.1.2 Temporal Vision	11
2.2.1.3 Chromatic Vision	12
2.2.2 Display Medium Considerations	13
2.2.3 Environment Considerations	13
2.3 Characteristics of Paper, CRT, and LCD Displays	14
2.3.1 Paper Displays	14
2.3.2 The Cathode Ray Tube (CRT)	15
2.3.3 The Liquid Crystal Display (LCD)	16
2.4 Environmental Assumptions	17
2.5 Spatial Vision	18
2.5.1 Resolution (Paper, CRT, LCD)	19
2.5.2 Luminance (CRT, LCD)	20
2.5.3 Luminance Contrast and Contrast Ratio (Paper, CRT, LCD)	24
2.5.3.1 Electronic Displays	24
2.5.3.2 Paper Displays	26
2.5.4 Luminance Uniformity (CRT, LCD)	27
2.5.5 Contrast Direction/Contrast Polarity (Paper, CRT, LCD)	28

TABLE OF CONTENTS (cont.)

2.5.5.1	Electronic Displays	28
2.5.5.2	Paper Displays	29
2.5.6	Convergence and Focus (CRT)	29
2.5.7	Symbol Alignment (CRT, LCD)	30
2.5.8	Defects and Line Failures (CRT)	31
2.5.9	Anti-Aliasing and Shades of Gray (CRT, LCD)	32
2.5.10	Viewing Angle (CRT, LCD)	33
2.6	Temporal Vision	34
2.6.1	Flicker and Refresh Rate (CRT, LCD)	34
2.6.2	Jitter (CRT, LCD)	37
2.7	Chromatic Vision (CRT, LCD)	38
2.8	Table of Conclusions and Summary	41
3.	INFORMATION PRESENTATION REQUIREMENTS FOR IAP CHARTS . . .	45
3.1	Overview of Chapter 3	45
3.1.1	How to Use the Information in Chapters 3 through 7	46
3.2	The IAP Chart User's Task	46
3.3	The IAP Chart Designer's Tool Box	49
4.	ORIENTING WITHIN THE IAP CHART	51
4.1	Overview of Chapter 4	51
4.2	The Visual Structure of an IAP Chart	55
4.3	Specifying Parts	58
4.3.1	Distinctive Visual Appearance	60
4.3.2	Standard Location	60
4.3.3	Methods for Defining Boundaries	60
4.4	Specifying Relationships	61
4.4.1	Same Hierarchical Level, Same Location	64

TABLE OF CONTENTS (cont.)

4.4.1.1	Proximity	64
4.4.1.2	Bounding	65
4.4.2	Same Hierarchical Level, Different Location	65
4.4.2.1	Similarity	66
4.4.2.2	Pointing	66
4.4.2.3	"Leading"	68
4.4.3	Different Levels, Same Location	68
4.4.3.1	Contrast	69
4.4.3.2	Interposition	73
4.4.4	Different Levels, Different Locations	74
4.5	Summary	75
5.	SEARCH AND LEGIBILITY	77
5.1	Overview of Chapter 5	77
5.2	Control of Eye Movements During Search	78
5.3	Font Characteristic Tools	79
5.3.1	Typeface	80
5.3.2	Font Size	83
5.3.3	Typeface Space Economy	89
5.3.4	Type Proportions	90
5.3.4.1	Character Stroke-to-Height Ratio	90
5.3.4.2	Variation in Stroke Width	90
5.3.4.3	Stroke Width or Typeface Weight	91
5.3.4.4	Ratio of x-Height to Overall Letter Height	91
5.3.5	Individual Character Confusions	92
5.3.6	Type Case	95
5.3.7	Inter-Character Spacing	96

TABLE OF CONTENTS (cont.)

5.3.8	Leading	97
5.3.9	Rotated Type	98
5.3.10	Type/Background Contrast	98
5.4	Symbol Characteristics Tools	98
5.4.1	Symbol Shape	100
5.4.1.1	Simplicity of Shape	101
5.4.1.2	Distinctive Global Shape	102
5.4.1.3	Simple Local Features	103
5.4.1.4	Strong Figure/Ground Relationship	104
5.4.2	Symbol Size	104
5.4.3	Symbols and Color	105
5.4.4	Achieving Symbol Legibility	106
5.5	Summary	106
6.	SEARCH AND PERIPHERAL VISION	107
6.1	Overview of Chapter 6	107
6.2	Information Highlighting Tools	108
6.2.1	Highlighting through Brightness	108
6.2.2	Highlighting through Bolding	108
6.2.3	Highlighting through Reverse Video	109
6.2.4	Highlighting through Blinking	110
6.2.5	Highlighting through Underlining	110
6.2.6	Highlighting through Boxing	110
6.2.7	Limitations of Highlighting	111
6.3	Information Coding Tools	112
6.3.1	Color Coding	112
6.3.1.1	Color Coding and Display Segmentation	113
6.3.1.2	Color Coding and Visual Search	114
6.3.1.3	Color Coding Land Surface Heights	117
6.3.1.4	Limitations on Color Coding	118
6.3.1.5	Colors to Use	119

TABLE OF CONTENTS (cont.)

6.3.2	Size Coding	123
6.3.	Shape Coding	123
6.4	Information Bounding Tools	124
6.4.1	Reducing Amount of Space to be Searched	124
6.4.2	Information bounding and the use of Columns	125
6.4.3	Reducing Inter-Item Interference	127
6.4.4	Information Density Measures	128
6.5	Summary	129
7.	EVALUATING THE USE OF THE DESIGN TOOLS	131
7.1	Overview of Chapter 7	131
7.2	Visual Balance	132
7.3	Information Density	133
7.4	Figure/Ground and Contrast	135
7.5	A Final Word on Using the Tool Box	137
8.	THE DESIGN PRINCIPLES	140
	REFERENCES	155

LIST OF FIGURES

Figure 1-1.	Example of an NOS IAP Chart	2
Figure 2-1.	The CIE Color System	39
Figure 2-2.	Use of the CIE Color System for Mapping Discriminable Colors	40
Figure 4-1.	Major Parts of the NOS IAP Chart	52
Figure 4-2.	Types of Formats used on IAP Charts	56
Figure 4-3.	Hierarchy	57
Figure 4-4.	Frames	59
Figure 4-5.	Use of Boundary Tools on NOS Charts	62
Figure 4-6.	Layering	63
Figure 4-7.	The Use of Bounding on NOS Charts	65
Figure 4-8.	Use of Pointing to Specify a Missed Approach on an NOS Chart	67
Figure 4-9.	Specifying Multiple Layers through Variations in Edge Contrast	69
Figure 4-10.	Specifying Multiple Layers through Variations in Brightness Contrast	70
Figure 4-11.	Brightness Contrast used for Layering on the Airport Section of an NOS Chart	70
Figure 4-12.	Variations in Line Weight	72
Figure 4-13.	Variations in Line Character	72
Figure 4-14.	Varying Multiple Layers through Interposition	73
Figure 5-1.	Variations in Stroke Width	82
Figure 5-2.	Font Sizes used on NOS Charts	84
Figure 5-3.	Measuring Point Size	86
Figure 5-4.	Variations in Actual Size for Typefaces having the same Point Size	86
Figure 5-5.	Some Typographic Terms	87
Figure 5-6.	Perceived Size Due to x-Height	87
Figure 5-7.	Differences in Typeface Space Economy	89
Figure 5-8.	Four Different Weights for the Same Typeface - Helvetica Condensed	91
Figure 5-9.	Condensed Versus Regular Helvetica	92
Figure 5-10.	Upper-Versus Lowercase Letter Discriminability	95
Figure 5-11.	Variations in Spacing Between Letters	96
Figure 5-12.	Loss of Contrast Between Text and background on an NOS Chart	99
Figure 5-13.	Common Types of Symbols used on IAP Charts	101
Figure 6-1.	Four Alternative Radio Frequency Layouts (from Multer et al., 1991)	126
Figure 7-1.	The "teeter-totter" Metaphor of Visual Balance	133
Figure 7-2.	An NOS Chart	136

LIST OF TABLES

Table 2-1.	Aerospace Recommendations Reviewed for CRTs	21
Table 2-2.	Recommendations for Mean Luminance Values for VDT Workstations . . .	22
Table 2-3.	Aerospace Recommendations for Screen Mean Luminance	23
Table 2-4.	Aerospace Recommendations Regarding Luminance Contrast	25
Table 2-5.	VDT Recommendations for Luminance Contrast Values	26
Table 2-6.	Aerospace Recommendations for Acceptable Large Area Non-Uniformities	27
Table 2-7.	VDT Recommendations for Acceptable Large Area Non-Uniformities	28
Table 2-8.	VDT Recommendations for Contrast Direction/Polarity	30
Table 2-9.	Aerospace Recommendations for Convergence	31
Table 2-10.	Aerospace Recommendations for Symbol Alignment	32
Table 2-11.	Aerospace Recommendations for Viewing Angle	34
Table 2-12.	Aerospace Recommendations for Refresh Rate and Flicker	35
Table 2-13.	VDT Recommendations for Refresh Rate and Flicker	36
Table 2-14.	Aerospace Recommendations for Allowable Jitter (for CRTs)	37
Table 2-15.	Summary of Conclusions	42
Table 4-1.	Types of Hierarchical Relations	64
Table 5-1.	Common Methods for Assessing Legibility	81
Table 5-2.	Confusable Characters	93
Table 5-3.	Optimal Dimension for Ensuring Maximum Discriminability of Simple Geometric Shapes	102
Table 6-1.	Two Examples of Recommended Colors of Topographic Maps	119
Table 6-2.	Colors that can be used by Color-blind Users	120
Table 6-3.	Bruce and Foster's (1982) Recommendations on Text/Background	121
Table 6-4.	Advisory Circular 25-11 Color Coding Schemes	122
Table 7-1.	Principles of Balance	134

EXECUTIVE SUMMARY

Instrument Approach Procedure (IAP) charts play a critical role in the safe and expeditious flow of traffic in and out of airports. Although their value is unquestioned, there is continuing interest in identifying modifications that can be made to these charts so as to improve their usability by the pilot. This Handbook is the first of a series of handbooks which address the issue of IAP chart improvement in design. The intent of this Handbook is twofold: (1) To review the relevant literature that might be applicable to improving the presentation of chart information to support effective and efficient access to information by the user; and (2) To develop guidance information, based upon this research, that can be easily accessed and implemented by the chart designer.

The first stage in the project involved performing an extensive literature review that encompassed the fields of human factors, cartography, psychophysics and perception, reading, information design, instructional design, and graphic design. The outcome was a bibliography of almost a thousand references. These references were then reviewed and relevant design information was extracted.

This design information was then organized and synthesized into a coherent structure through the use of a metaphor called the "tool box." The tool box metaphor is intended to convey the idea that the chart designer has available a number of design tools that can be used to embody information on a chart. An effective chart is the result of the strategic and logical application of these tools. The major portion of the Handbook consists of descriptions of each tool, examples of how they might be used, reviews of any studies that have been conducted which have identified when a tool should or should not be used, and an explanation of the logic of how that tool should be used to convey a specific meaning to the chart user.

The Handbook is intended to offer the chart designer guidance information that can aid in developing charts which clearly present a meaningful visual structure. To be most effective, this visual structure must be based upon a sensible organizational logic. The development of an organizational logic involves looking at the information needs of the pilot and determining which information elements are most important, which elements tend to be used together, and how each information element relates to the other elements. Issues pertaining to organizational logic clearly involve the cognitive aspects of chart use. These issues will be addressed in a second handbook, currently being developed.

1. INTRODUCTION

1.1 OBJECTIVES AND STRUCTURE OF THE HANDBOOK

Instrument Approach Procedure (IAP) charts (see Figure 1-1¹) play a critical role in the safe and expeditious flow of traffic in and out of airports. Although their value is unquestioned, there is continuing interest in identifying modifications that can be made to these charts so as to improve their usability by the pilot. This Handbook attempts to provide useful, research-based guidance information that suggests the types of changes in the visual presentation of IAP chart information that can contribute to easier accessing and recognizing of information on the chart.

The scope of this Handbook has been constrained in several ways. First, *the Handbook is limited to factors that can affect perceptual interaction with the IAP chart*. Included are issues of screen quality, supporting the user's ability to visually orient on the chart and easily find that information specifically of interest, and legibility of alphanumeric information. The Handbook does *not* address issues of a "cognitive" nature, such as where each type of information should be located on the chart or new ways of presenting information that might make understanding the information easier for the user. In addition, the Handbook assumes the use of a "static," two-dimensional display. The opportunities provided by a dynamic display that can change the form and types of information presented in response to user choices is not considered.

The Handbook consists of seven major chapters. Chapter 2 reviews the minimum performance requirements for adequate display quality of paper and electronic displays used to present IAP charts. Topics that are covered include required luminance levels, flicker and refresh rates, and viewing angle.

Chapters 3 through 7 provide guidance on how to present approach-plate information in order to support the user's accessing that information and correctly reading it. Chapter 3 sets the stage by looking at how users perceptually interact with IAP charts, suggesting that two stages are involved. First, the user must orient within the chart so as to find that part of the chart most likely to contain the information that is needed. Orienting is then followed by a search process that enables the user to find, within that part of the chart, the desired information. Chapters 4, 5 and 6 then describe the design tools that are available to the IAP chart designer to support each process.

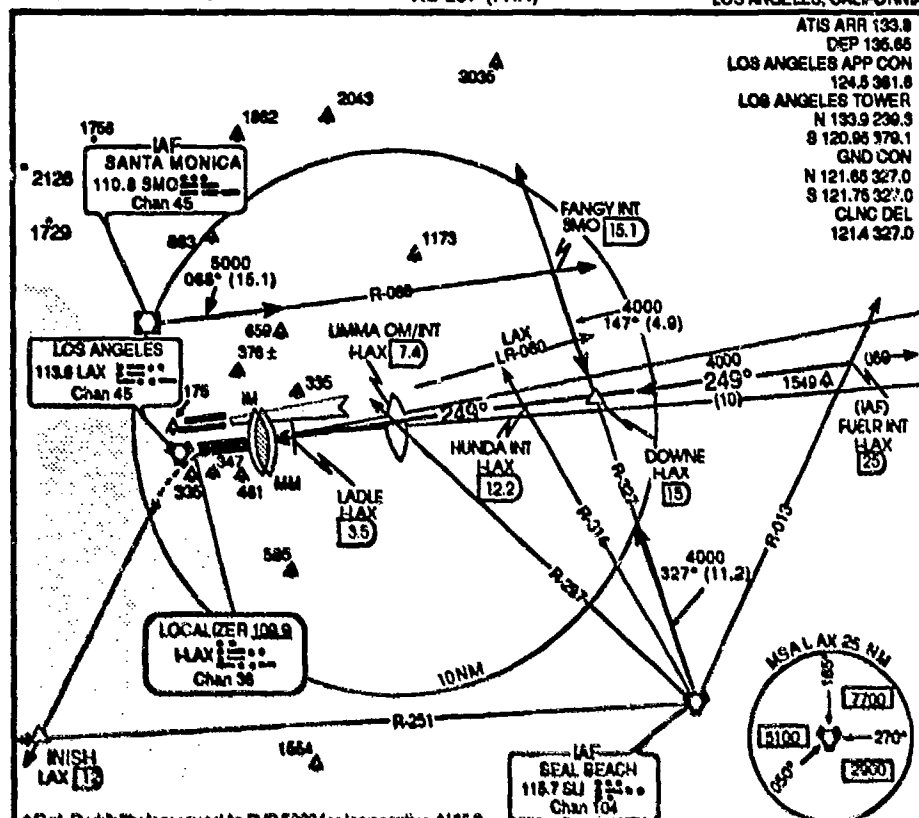
Each application of a design tool must be assessed both in terms of how it supports the orienting or search process and the overall usability of the chart. Chapter 7 offers some general criteria that can be used to ensure that all of the visual elements presented on the IAP chart work together to produce a coherent and visually organized whole. Finally, all of the design guidance principles are listed in an Appendix.

¹ The NOS charts displayed in this Handbook were constructed using a Macintosh computer. Every effort was made to duplicate actual NOS charts to the extent possible. However, some differences remain, for example, in the typeface used. These differences, however, do not impact the utility of the Macintosh charts in demonstrating points of discussion.

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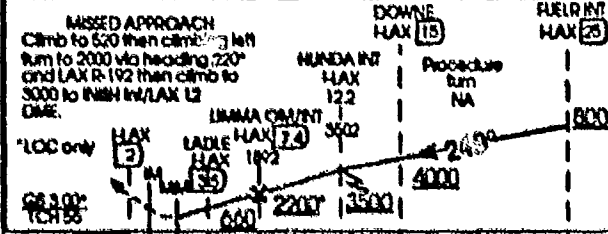
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LOS ANGELES INTL (LAX)
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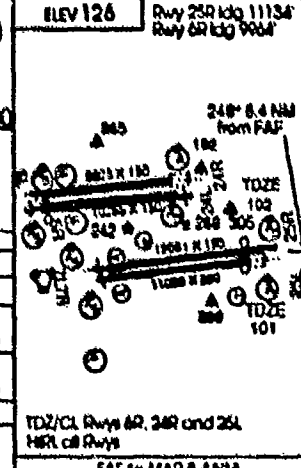
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 DEP 136.65
 LOS ANGELES APP CON
 124.5 361.8
 LOS ANGELES TOWER
 N 133.9 230.3
 S 120.66 378.1
 GND CON
 N 121.66 327.0
 S 121.76 327.0
 CLNC DEL
 121.4 327.0

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Figure 1-1. Example of an NOS IAP chart.

1.2 CAVEATS

Although maps and charts of all kinds are a common part of our lives, surprisingly little is known about the perceptual and cognitive processes that determine how easy maps are to use (Taylor & Hopkin, 1975). Maps are a unique form of visual information display and, in theory, the vast amount of information about how to design effective displays, developed through the efforts of human factors researchers and user-computer interface designers, should apply. Similarly, maps are a form of printed material and what we know about effective typographic and page layout design also should apply.

Although visual displays and printed material are two well-researched areas of information presentation, surprisingly little attention has been devoted to maps themselves. Maps are clearly a complex form of information presentation. For this reason, concern has been expressed as to the applicability of research results that have been obtained in the related domains of visual information displays and printed media. Two of the leading experts in aviation maps and charts express this concern:

The contribution of ergonomics to solving this problem [of map overcrowding and lack of legibility] has been small. Although ergonomic textbooks and handbooks provide many recommendations on the contents, layout and coding of displayed information, it is not immediately obvious how far such recommendations apply to maps. Perhaps large scale topographical maps are so complex as information displays that standard ergonomic findings do not remain valid for them (Taylor & Hopkin, 1975, p. 197).

To complicate matters further, IAP charts are a unique type of map, differing in important ways from other types of maps. IAP charts differ structurally from road maps and atlases in that they consist not only of the "map part" but also include small amounts of running text, tables, and other forms of print material organizations. Consequently, they are not simply "maps" presenting landmarks, roads, and other geographical information. In addition, the conditions under which IAP charts are used differ greatly from other types of maps. Atlases and other forms of topographical maps are usually used in home or office settings under controlled lighting conditions with the user sitting in a non-moving chair. Issues of insufficient light, vibration, and turbulence are obviously not factors. Also, the atlas user is not under the same types of time constraints as the IAP chart user nor is the atlas user performing other complex tasks (flying the airplane, talking with air traffic control, etc.) at the same time.

The guidance information described in this handbook is obviously constrained by serious differences between IAP chart use and the situations in which the experimental data were originally collected. Because of limitations in the amount and quality of research aimed at maps in general, and IAP charts in particular, research conclusions in other, related domains have been reviewed. Clearly, guidance provided by this type of research is subject to serious questions as to how well it applies to the IAP chart domain. However, even though the results do not conclusively apply, they are of value in that they do offer some suggestions on how certain design variables *might* improve the usability of approach plates. It is critical to remember, though, that many of the conclusions suggested here are necessarily tentative and require evaluation performed under conditions comparable to the flight environment.

2. DISPLAY IMAGE QUALITY

2.1 OVERVIEW OF CHAPTER 2

Effective information presentation requires that the medium by which the information is conveyed (paper, CRT, LCD, etc.) be capable of displaying that information sufficiently to support the visual system's ability to easily detect it. The performance requirements for a display medium are extensive and often complex. This chapter provides a brief overview of the human factors issues related to *image quality* of paper, CRT, and LCD displays. A thorough review of this topic exceeds the constraints of a single chapter. Instead, the attempt has been made to provide a brief overview of the more critical factors, together with accepted human factors standards for defining required display performance values for each factor.

Two objectives have guided the selection and organization of the information provided here. For the reader who is not experienced with display performance requirements, this chapter provides a general overview of the topic that should be sufficient to enable the display designer to assess the adequacy of a display intended for use in presenting IAP charts. References to literature which provide more in-depth coverage of topics are included, where appropriate, to enable the interested reader to obtain additional information. The reader who is already familiar with the issues surrounding display quality is likely to find the descriptive information presented in this chapter familiar and less useful. However, this reader will find a compilation of display quality standards that have been proposed by both aviation and office systems human factors organizations. These standards, organized by topic, should provide a useful reference for even the most experienced display designer.

This chapter has been organized into six sections. Section 2.2 provides a brief overview of the basic issue that underlies the problem of achieving sufficient display quality. This issue, simply stated, is that the user and the display medium can be seen as individual systems that support information flow to varying degrees. Each system has its own strengths and limitations with respect to the types of information that can be supported. Effective display design, from a human factors perspective, means that the display system is designed to complement the user in terms of his/her own visual system strengths and weaknesses. Insensitivity on the part of the human visual system must be compensated for by the design of a display medium that can amplify that information so as to overcome visual system limitations.

This relationship between the user and the display medium is complicated by the role of the environment in which the user and display medium must function. This complication takes the form, once again, of a limitation on the part of the user, in the sense that the impact of the environment is likely to appear as an inability, on the part of the user, to detect or otherwise respond to information provided by the display medium. For example, vibration of the cockpit and the user can reduce the user's sensitivity to visual information that can otherwise be detected. Once again, the solution is to design the display medium so as to compensate for user limitations.

Treating the user, the display medium, and the use environment as an integrated information flow system encourages a focus on how each part of the system contributes to, or hinders, the flow of specific types of information. In keeping with this theme, Section 2.3 looks at three types of display media that might be used to present IAP charts: paper, CRT, and LCD. The objective of this section is to briefly review the strengths and limitations of each medium in order to identify the more critical ways in which information transfer might be hindered by each medium. This description is intended to provide a general conceptual framework for understanding the recommended display performance standards described later in this chapter.

Environmental factors are then reviewed in Section 2.4. Again, the objective is to specify those factors, inherent in the cockpit environment, which are likely to impact visual system performance, resulting in the need for support of the visual system through better display characteristics. The two most important factors to be reviewed are ambient lighting within the cockpit and vibration. Unfortunately, it is not possible to describe the specific impacts of these factors in a quantitative form. The ideal, of course, would be to define them in such a way that they could be represented by simply dropping a variable into existing equations for defining display requirements. In lieu of a quantitative approach, the alternative is to describe these effects qualitatively, with the admonition that all design decisions must anticipate their effects.

The remaining three sections of the chapter review the various factors that affect display quality. These factors have been categorized into three types: spatial, temporal, and chromatic (Snyder, 1988). *Spatial variables* affect the ability of the eye to detect information distributed along the vertical and horizontal dimensions of the display. The fundamental concept underlying the spatial variables is the differentiation of information by means of variations in luminance intensity. Simply speaking, information is detected on a display because patterns of display locations are visually different from the background and neighboring items. These patterns represent information. For example, each alphanumeric character is comprised of its own set of display elements which are determined by the shape of the character together with the intended location of the character on the screen. The pattern of distinctive elements enables us to differentiate individual characters. Differentiation of pattern elements takes place on the basis of variations in luminance intensity. Factors that influence the use of luminance intensity are addressed in Section 2.5.

Information presentation is also affected by *temporal variables*. Typically, we think of temporal variables as involving the occurrence of some event that begins at some point in time, unfolds during a defined temporal segment, and then ends at some later point. The use of electronic display media brings in an additional aspect of temporal variation that is of central concern to this chapter. Electronic displays involve the sequential presentation of information. For example, information on a CRT appears because of the operation of an electronic beam gun that activates patterns of phosphors. Phosphor activation takes time and must be constantly repeated as the phosphor quickly loses its brightness. This process of updating the display is a form of temporal variation that is foreign to our visual systems as they function in the everyday world. Not surprisingly, this process can be extremely disruptive to visual performance if it does not take place in a fashion that is unnoticed by the eye. Temporal variables are reviewed in Section 2.6.

The third set of factors are *chromatic variables*, which pertain to visual response to color. Although current paper IAP charts do not use color, it is quite likely that color will be used extensively on

electronic displays. Consequently, issues related to the display of color on CRT and LCD displays are addressed in Section 2.7.

For each of the three dimensions, the issue is developing a display that functions in the range of physical values that can be handled by the visual system. As Snyder (1988) points out, existing displays cannot support the ideal conditions desired for the visual system, including the capability to present very small spatial detail, a temporally stable view with no flicker, and an almost infinite range of colors. The issue, then, is to determine the minimum standards that must be met if the display is to be usable by the user, keeping in mind that tradeoffs, such as cost, are involved.

For each of the display quality factors reviewed in Sections 2.5, 2.6, and 2.7, the attempt has been made to recommend minimum performance requirements. These recommendations have been based on two sets of standards. The most extensive body of research has been performed in an attempt to identify the requirements for CRT displays used in the office environment. Although the application of the resulting standards to the aviation environment is clearly problematic, these standards are reviewed simply because they provide additional data which, if used with caution, may be useful in making decisions for displays to be used for presenting IAP charts. A second set of standards are reviewed which have been developed for the aviation environment by such organizations as ARINC (Aeronautical Radio, Inc.), the Society for Automotive Engineers, and the military.

Both the office and aviation standards focus almost exclusively on CRTs as the electronic display medium. Currently, there are no relevant aviation or office environment recommendations for flat panel displays such as LCDs. In addition, the bulk of the research aimed at deriving human factors recommendations for LCDs has been performed by private corporations. Consequently, there is very little experimental data available in the public literature. Although the attempt has been made to provide recommendations for LCDs, these recommendations must be treated with special caution.

Recommendations for display quality issues pertaining to paper presentation of IAP charts are also vague with regard to the parameters identified above. Requirements for such critical parameters as printing resolution and symbol-to-background contrast ratio appear to be non-existent. In those cases where specific aviation recommendations are not available, common practice is used as the standard.

One final point should be made about the recommendations described in this chapter. Many of the conclusions presented are stated in two ways. The first version of the conclusion begins with the phrase "For the unaided observer...." For example, "For the unaided observer, all symbols should be of sufficient height to ensure adequate legibility in all viewing situations." This version of the conclusion is oriented towards users of this Handbook who do not have access to the equipment required to accurately measure the display's performance on that parameter. The objective is to provide, whenever feasible, alternative tools that can support the evaluation process.

A second version of the conclusion specifies the minimum acceptable parameter value, against which the performance of the display can be evaluated either by means of the manufacturer's specifications for the display or by conducting the appropriate measurements. Additional

guidance for conducting these evaluations can be found in The Aerospace Recommended Practice, entitled *Photometric and Colorimetric Measurement Procedures for Airborne Direct View CRT Displays* (ARP 1782, 1989).

Actual measurement of each display quality factor, by the display manufacturer, designer, or evaluator should be supplemented by the observational methods described in the first version of the conclusions. This process is recommended for the simple reason that many of the performance requirements described in this chapter are based upon experimental data and expert opinion oriented towards non-IAP chart situations. The unique conditions in which IAP charts are likely to be used may require stricter performance requirements than are suggested by the requirements described in this chapter. Visual evaluation of these factors under the conditions of normal IAP chart use should be performed whenever possible to ensure that each display is usable.

2.2 THE USER, THE DISPLAY MEDIUM, AND THE ENVIRONMENT

At its simplest level, the purpose of IAP charts, whether paper or electronic, is to transfer information from the chart to the user. This process of information transfer takes place by means of light. Chart information is embodied in patterns of light that are either generated by the display (CRT or LCD) or arise because of reflection off of the display's surface (paper). These light patterns travel to the eye, initiating the process of perception that results in the detection of the information embodied in the patterned light. The amount and quality of information transferred depends both on the properties of the display medium and the limitations of the visual system. When the acceptable limits on either system are exceeded, information transfer is necessarily constrained. Electronic and paper displays are limited as to the amount and quality of the light patterns they can emit or reflect. Similarly, the visual system possesses its own set of sensitivities and limitations that determine the conditions under which visual performance is likely to be sufficiently effective to achieve adequate performance.

2.2.1 Visual System Considerations

The objective of the visual process is to detect and differentiate individual patterns of information conveyed by means of light. These patterns correspond to the objects and events of our world. Differentiation of objects takes place by perceiving differences in color and brightness in the light patterns that reach the retina. Three dimensions of visual performance are especially important in assessing the quality of a display. These dimensions are:

- **Spatial vision:** The ability of the eye to detect patterns of information in light;
- **Temporal vision:** The responsiveness of the eye to pattern change;
- **Chromatic vision:** The sensitivity of the eye to color.

Each of these types of vision is reviewed below.

2.2.1.1 SPATIAL VISION

Information presented on an IAP chart is conveyed to the eye in the form of patterns of light that are actually variations in the relative luminance of the pattern elements. These luminance differences must be sufficiently large to enable the eye to differentiate between them. With respect to IAP charts, the issue of pattern detection is most critical as it pertains to the ability of the eye to detect the substantial amounts of small detail, such as symbols and alphanumeric characters, that can appear on a chart. The ability of the eye to detect this small detail depends on a number of factors relating to variations in the characteristics of the light available to the eye and the eye's effectiveness in responding to these variations.

Two sources of light for carrying information are available. Most of the light that reaches the eye is reflected light. Reflected light refers to the light from a light source that bounces off of a surface and then travels to the eye. Light from the sun is one source for reflected light. Typically, we don't look at the sun directly. Instead, we are able to utilize the reflected light that originated in the sun as a means of differentiating objects around us. When we are indoors, the luminance source is usually a lamp of some type. Again, we tend to use the reflected rather than direct light from that source.

In the case of IAP charts, the type of light used depends upon the display medium. Paper charts are read only by means of light reflected off of the chart. Electronic displays represent a very different situation in that CRTs and LCDs emit their own light. However, reflected light also plays a role in that the light available from an electronic display is a combination of emitted and reflected light. In this situation, reflected light can cause problems for the visual system, the obvious case being that of glare.

Regardless of whether the light is reflected or emitted, the basic functioning of the visual system is generally the same. Light energy is transformed by photoreceptive material in the retina, located at the rear of the eye ball, into neural pulses that are then processed by the cognitive system. These neural pulses reflect the pattern of information represented in the light.

The pattern of neural pulses is a consequence of the ability of the cells located in the retina to detect changes in the intensity or color of the light available to the eye. In the case of IAP charts, this capability translates into the ability to discriminate individual alphanumeric characters and symbols. This capability is affected by the conditions under which the object is being perceived. The visual system is best able to detect small, detailed information under bright lighting conditions. This is one reason why reading lamps are commonly used for tasks that involve seeing small detail, such as reading or sewing.

The relationship between luminance conditions and the ability of the eye to detect small detail is a consequence of the physiology of the retina. There are two types of photoreceptor cells located in the retina. Under bright light, the cones are the dominant photoreceptor cells while rods become dominant under dark conditions. Together, the two types of cells enable the visual system to function under a broad range of lighting conditions.

There is also a relationship between type of photoreceptor cell, lighting condition, and sensitivity to detail. Cones require substantially higher levels of light to function in comparison to rods. The reason for this is that cones have a one-to-one mapping with neurons in the visual system. This mapping supports greater preservation of detail in that each cone's response travels to the higher

levels of processing in the visual system. Rods, in contrast, achieve their ability to respond to very low amounts of light from the many-to-one mapping of rods to visual system neurons. The energy emitted by small amounts of light that reach individual rods belonging to a common group is summed together, enabling the activation of the visual neuron to which those rods, as a group, are connected. This enhanced sensitivity to light is accompanied, however, by a reduced sensitivity to detail. Each rod's individual response to light patterns is summed together with all of the other rods belonging to a common group. Consequently, rods are necessarily less sensitive to detail. The result is that, although we are able to see objects under low lighting conditions, we are only able to see gross shapes and forms. We can see enough to get around, for example, but we are unable to read a book or thread a needle.

The importance of the cone/rod distinction for the IAP chart situation is the need to ensure that sufficient light is provided to support vision by means of the cone system. IAP charts contain a substantial amount of information that is usually very small. It is also important to ensure that the size of the detail is sufficient to be detectable. Very small objects have correspondingly small differences in luminance. These luminance differences must be sufficiently large to ensure consistent detection by the visual system.

To this point, the emphasis has been on the ability of the eye to discriminate between light patterns that correspond to different objects. Luminance differences have been assumed to signal differences between objects. This is not always the case, however, when electronic displays are used. Specifically, the problem concerns the fact that information is formed on an electronic display by means of minute elements (called picture elements or *pixels*) that are so small and close together they appear to form continuous lines. In effect, the eye is tricked into seeing continuity even though the actual underlying elements are discrete. As will be shown later in this chapter, an important part of the process of evaluating displays involves assessing their effectiveness in enabling larger coherent characters and symbols to appear by means of pixels.

A separate set of considerations that influence pattern vision affect the visual system *before* light reaches the retina. This set of factors are, in a sense, mechanical in nature and each introduces its own form of distortion to the light. Light enters the eye through the cornea and then passes through an opening called the pupil. Distortion from the cornea can take place in several ways. First, the curved shape of the cornea causes the light to curve. In addition, scarring and clouding can occur that reduce the amount of light able to pass through. The iris also has an important influence because it controls the size of the pupil, which, in turn, determines the amount of light allowed to enter the eye. Under bright ambient conditions, the pupil opening is small, enabling mostly focused light to reach the retina. Under dim light, the pupil expands, through contraction of the iris, to allow more, less directed light to enter.

The light then reaches the lens, which is used to manipulate the curvature of the light so as to ensure that the light is focused appropriately on the retina. Objects located close to the eye cause the lens to bend into a more convex shape. The lens is flatter for objects farther away. This process is called accommodation. The process of accommodation is especially critical in the case of the IAP chart user in that the pilot may have to repeatedly look out the window (e.g. for traffic), then at objects located much closer, such as the IAP chart.

Older eyes may also suffer from a clouding of the lens that reduces the amount of light able to pass through. As the lens ages, it also tends to become stiffer, reducing the ability of the lens to

curve as required when looking at objects that are located close to the eye. Finally, the light must then pass through the vitreous fluid that fills the eye ball. Older eyes may have greater amounts of solid matter floating in the vitreous fluid which again can reduce the amount of light, as well as causing the light waves to distort as they strike the solid matter.

Regardless of age, many individuals suffer from an inability to properly focus the light onto the retina. Near-sightedness and far-sightedness are also common conditions that can be largely compensated for through corrective lens. Problems in visual functioning due to poor eye sight or age are of critical importance to display quality evaluation. Displays must be designed, to the extent possible, to compensate for expected changes in visual performance that are likely to occur in many pilots. Although many of these problems can be corrected, there still remain difficulties that arise through the correction process. One of these problems is the fact that corrective lenses tend to decrease the overall amount of light that reaches the retina. Also, the introduction of certain types of correction may impact the posture of the user. One of the most common problems arises through the use of bifocals because the user must position the head correctly so as to ensure the ability to look through the corrected part of the lens. The result is the tendency to raise the head so as to look through the lower part of the lens. The result can be excessive stress to the neck and back muscles.

As this section has shown, the ability to detect detailed information is governed by a variety of factors, including the optical properties of the eye, the density of photoreceptors across the retina, and the degree of luminous difference provided by the environment to the eye. All of these factors will influence the user's ability to see the information presented on an IAP chart. The fact that there is a 50% reduction in the amount of illumination that reaches the retina at the age of 50 years compared to 20 (Degani, 1991) argues for the need to use conservative design guidelines. This consideration explains why the decision to use especially strict values was made in developing the recommendations described later in this chapter.

2.2.1.2 TEMPORAL VISION

Temporal vision, as the name suggests, refers to the ability of the visual system to detect change. Although the use of static displays, such as IAP charts, would suggest that temporal vision does not play a role in chart perception, temporal vision is, in fact, a critical element factor with electronic displays. As Section 2.3 will describe, electronic displays, even those that present static information such as IAP charts, undergo constant change, in the form of the repeated refreshing of the screen. The previous section pointed out that the eye must be tricked into seeing continuous lines formed by means of very small pixels. Similarly, the eye must also be tricked into seeing continuity over time even though the screen is actually constantly changing. If this refresh process occurs too slowly, the screen will appear to flicker.

Perception of temporal change such as flicker is related to the rod and cone system described earlier. Cones are located primarily in the central part of the retina, an area called the fovea. When we look directly at an object, we position our eyes so as to allow the fovea to face the object. This allows the cones to be oriented towards the object, so as to take advantage of the cone's greater sensitivity to detail.

Rods are located predominantly away from the fovea. This design is advantageous because rods are not only more sensitive to light but they are also more sensitive to movement. When a

moving object comes into the field of view from the left or right, it first enters peripheral vision. The rods are quickly activated and help to direct the fovea towards that object so as to enable the cones to use their sensitivity to detail to recognize the moving object.

The relevance of the rod/cone distinction to electronic displays may not be immediately obvious from this description. There will not be moving objects on near-generation IAP charts. Nonetheless, peripheral vision and the rod system play an important role in detecting temporal change in displays due to flicker and jitter. For the design evaluator, peripheral vision is a useful tool for evaluating display quality. For the display user, peripheral vision will play a critical role in guiding eye movements when seeking specific information presented on a chart. This latter process will be described in Chapter 3.

2.2.1.3 CHROMATIC VISION

A third important aspect of vision is chromatic vision, the ability to detect differences in color. Color is currently not used on paper IAP charts but it is likely that color will be available on electronic charts as a means of coding similar types of information and as a tool for supporting the chart user's ability to detect small information elements on a chart. Since the visual system is very sensitive to color, color is a potentially valuable tool for IAP charts. As will be shown in Chapters 4 and 6 of this Handbook, effective use of color can improve symbol detection and provide a valuable tool for supporting chart information organization.

The light that fills our world is full of color. What is not obvious is that the color we see can be produced in a variety of ways. Most colors can be produced through the combination of a variety of wavelengths. For this reason, most light sources can only be described by considering their *spectral composition*, i.e. the amount of energy contributed to the total by each wavelength. The spectral composition of a light source determines its perceived color but it is not possible for a human observer to determine the spectral composition of an object by looking at it.

The color we see is determined not only by the spectral composition of the light but also by the light conditions surrounding the object. Good color acuity, like spatial acuity, requires high light levels (i.e. 3.18 cd/m²) because color is perceived by means of the cones. For cockpit displays the implication is that color should be used to convey important information only when adequate cockpit and display lighting can be ensured.

The appearance of a colored object can be described along three relatively independent dimensions. The *hue* of an object refers to that aspect to which we usually assign color names, such as red, blue, or purple. There are four unique hues that can only be described by using their own color names: blue, green, red, and yellow. Other colors are described by combining these four basic colors, for example, blue-green or yellowish-red. "Colored" objects which do not appear to possess any hue are termed *achromatic*, such as gray, black, or white. Those objects that do possess color are termed *chromatic*.

A second aspect of colored objects is their *brightness* or *lightness*. These terms refer to the perceived intensity of the light reflected or emitted from the object. Objects with an equivalent hue may still appear brighter or lighter relative to each other, thus aiding adequate discrimination.

Finally, an object's color may vary in terms of its *saturation* or *chroma*. This aspect refers to color purity: The amount of saturation describes the color's deviation from a pure white. For example, darkening a pink by adding more red corresponds to increasing saturation.

Because the perception of color is due to stimulation of the cone cells of the retina, at very low light levels (when the visual system is dark adapted) objects will appear to lose color and look white or gray. For this reason, it is recommended that for color perception the minimum radiant energy coming from the object should exceed 0.001 cd/m^2 (Boff & Lincoln, 1988, p. 337).

Wavelength and brightness are not independent dimensions, in that the visual system is differentially sensitive to different wavelengths. The same amount of energy contained in light of 380 nm will not cause the same brightness sensation if contained in light of 550 nm. The practical implication of this is that blue symbols are much harder to discriminate on a dark display screen than green or yellow symbols even if they are matched in total light energy output.

Although color is a potentially valuable tool, it is important to remember that partial color-blindness is a common phenomenon. This disability can be compensated for through careful selection of the colors used.

This very brief description of some of the major characteristics of the visual system is intended to review some phenomena that form the basis for design decisions. That is, take advantage of what the visual system is good at and find ways to compensate for its limitations. The visual system has its own requirements with respect to the types of visual stimulation to which it is sensitive. In evaluating the performance of a display, need to take into the account the specific requirements of the visual system. Not enough to measure absolute performance requirements.

2.2.2 Display Medium Considerations

Our visual systems, in effect, serve as transducers of patterns of energy. As transducers, certain aspects of light energy are lost due to the insensitivity of the visual system to those aspects. Similarly, displays are transducers in that they translate electrical energy into patterns of information that we can see. In this process, however, some aspects of electrical energy are lost. A signal that passes through a display is likely to lose some of its amplitude. In the case of square waves, this can mean the loss of crisp and distinct edges, the result being a blurred image. Each medium has its own strengths and weaknesses with respect to the ability to present information, which will be reviewed in somewhat more detail in Section 2.3 of this chapter.

2.2.3 Environment Considerations

The effectiveness of information transfer is also affected by factors outside of the display medium and the visual system. The environment provides its own sources of light which can inhibit the ability of the display to adequately convey information to the visual system.

A second important environmental factor is vibration. Vibration is likely to have an effect on performance by inhibiting the ability of the eye to stabilize on the display in order to read the image. Both of these factors are discussed in somewhat more detail in Section 2.4 of this chapter.

Adequate display quality must take into account the expected losses in information that can occur in the visual system, the display medium, and as a consequence of environmental factors.

Although the visual system is able to adjust to a wide range of viewing conditions, this compensation necessarily brings with it the risk of negative side effects, such as reduced efficiency, visual strain, and fatigue.

2.3 CHARACTERISTICS OF PAPER, CRT, AND LCD DISPLAYS

Each display medium possesses its own unique advantages and disadvantages. This section briefly describes how each medium works, and the likely impact on display quality.

2.3.1 Paper Displays

The paper medium possesses a number of characteristics which make it quite unique when compared to electronic displays. In terms of spatial resolution, paper currently supports the highest level of resolution of the three display media. Printed characters are typically sharper than electronic characters for the simple reason that the approximately 600 dots per inch that is standard for typeset paper displays is much greater than even the highest resolution CRT, which can support approximately 170 dots per inch (Pluche & Hansman, 1990). The consequence is that the image on electronic displays appears somewhat blurred and less distinct.

In addition, paper has the advantage that the user can control the angle and distance of the page relative to the visual system. In this way, problems with insufficient character and symbol sizes, and limitations in visual system functioning can be compensated for.

There are several variables pertaining to paper composition that can impact the effectiveness of the display. The glossiness of the paper affects the amount of and type of light reflection off of the page. High gloss paper should be avoided for this reason. Paper thickness is also a consideration in that printing of both sides of the page occurs. Although light weight has obvious advantages, lightness of weight is achieved at the consequence of paper thinness, which can allow the back side of the page to partially mask information presented on the front of that page.

With respect to issues of temporal performance, the paper medium is the most stable for the obvious reason that it does not emit light that must be continuously refreshed. Paper is a reflective rather than light emitting medium. The obvious consequence of this difference is that the perceived contrast of a dark symbol on a light background remains constant as the ambient illumination level changes. Contrast is a function of the combined emitted and reflected light. As the amount of light changes so does the contrast. However, for a light emitting device, such as a CRT or LCD, the contrast between dark and light areas is constant independent of the surrounding lighting. As ambient illumination increases, the ratio of luminance differences between symbology and background (contrast ratio) will decrease. This reduction in contrast is due to several factors including increased reflected glare and the decreased contrast sensitivity of the eye due to adaptation to higher light levels.

Because paper IAP charts do not use color, there are no chromatic variables to consider.

2.3.2 The Cathode Ray Tube (CRT)

CRTs are currently the dominant technology used for cockpit displays. The CRT consists of an evacuated glass tube with an electron gun at one end. As the electron beam is deflected it selectively lights up different parts of the screen facing the user. The degree to which each point or picture element (pixel) lights up is a function of the intensity of the electron beam hitting it and the characteristics of the light-emitting phosphor coated onto the screen. Different phosphors will light up in different colors and with different light outputs.

The two most common types of CRTs are *refreshed* CRTs and *storage* CRTs. Refreshed CRTs must continually re-write the image to ensure that it appears stable and flicker-free to the user. Storage CRTs, in contrast, can maintain an image on the screen without the need for regeneration. Among these two broad types of CRTs are many subclasses which can vary in a number of ways, including how the electron beam is formed, how it is focused, and how it is deflected.

The most common version of the refreshed CRT, called a TV raster or raster scan, creates an image on the screen by repeatedly moving the electron beam across the screen face in lines. This scanning process is similar to the way a conventional television works. By turning the beam on and off at various times an image is created on the screen. Once the beam reaches the bottom of the screen it returns to the top and begins again. Another type of refresh CRT, the stroke character CRT, guides the electron beam over the path that forms a character. The beam first writes one symbol, then the next. Once the last symbol is written it repeats the cycle.

A storage CRT has two electron guns: a writing gun and a flooding gun. The writing gun "charges up" those areas which are to become luminous. The flooding gun then bathes the entire screen with low energy electrons. A secondary emission from the "charged" phosphors causes those areas to glow. Changing the image usually requires rewriting the entire screen. For this reason, storage CRTs are less popular for text-editing word processors. Most of the research that has been conducted on human factors requirements for CRTs has used raster scan CRTs and most existing cockpit CRTs use refresh CRTs. The performance requirements of CRTs described in this chapter will address only refresh CRTs.

Color CRTs are created by placing phosphors having different dominant wavelengths in an array across the screen face. Usually only blue, green, and red are used. A variety of colors are perceived because the visual system will integrate these combinations if they are located very close to each other spatially. An alternative approach, used by penetration type color CRTs, places different phosphors in layers upon the screen. Depending upon how far the beam penetrates these layers different phosphors will glow.

In terms of spatial vision, CRTs suffer from the problem that activation of a phosphor is not an all-or-none process. When a phosphor is activated, the pattern of activation follows a normal distribution: activation is greatest at the center of the phosphor and falls off gradually towards the edges. The consequence is that edges between phosphors are blurred.

With respect to temporal performance, CRTs suffer from two major limitations. First, the constant rewriting of the screen can cause the image to flicker if the refresh rate is too slow. In addition, when refreshing the screen, poorly designed CRTs can fail to scan the same path. Deviations from this path, either above or below, can cause the screen to jitter. The represented image may appear to be changing shape continuously.

In terms of chromatic problems, CRTs suffer from the difficulty that high ambient illumination conditions can cause the screen to wash out. Not only is luminance contrast reduced but also colors will appear faded or disappear entirely.

2.3.3 The Liquid Crystal Display (LCD)

Liquid Crystal Display (LCD) technology is undergoing rapid development at the present time. A number of different technologies are being explored, and it is difficult to determine which approach is likely to become the industry standard. For this reason, only the most general characteristics of LCDs are described. Additional information on new LCD technologies can be found in Pluche and Hansman (1990).

An LCD operates in a fundamentally different way than a CRT. CRTs are light emitting devices in that phosphors are activated so as to produce patterns of light. LCDs, in contrast, are essentially light modulating devices. As light passes through an LCD from behind, certain optical properties of the liquid crystals either permit the light to pass through unchanged, or scatter the light and absorb it resulting in a dark spot on the screen. These optical properties are governed by the alignment of the crystal molecules in particular directions. Because these crystals will actually move or align themselves with an externally applied electric field (hence the name "liquid crystals"), areas of the screen can be darkened or brightened by selectively applying electric fields. The pattern of bright and dark areas, defined by the shape of the applied electric field results in the production of graphic or alphanumeric characters on the screen.

Color may be generated in an LCD display in several ways. A common approach is to place colored filters on the surface of the liquid crystal cell. As the light penetrates the filters, selective wavelengths are absorbed. Those wavelengths that are not absorbed determine the color that is produced. By systematically arranging three differently colored dots over the pixels, a variety of colors can be achieved by varying the intensity of emitted light from each pixel. This process is similar to color generation in a CRT.

A second approach is to strobe three different colored lights behind the liquid crystal surface. Because the eye has a limited amount of temporal resolution the intensity of light passing through the pixel on each flash will govern the perception of color.

A third approach is to "dope" some liquid crystals with chemicals that absorb specific light waves depending upon their tilt. If the applied electric field is controlled precisely, the amount of tilt can be controlled and particular wavelengths will be absorbed. This approach is only now reaching the marketplace.

LCDs possess a number of advantages over CRT displays, including lower power consumption, lower weight, and greater reliability (Rausch, 1988).

With respect to spatial performance, the major challenges in producing high quality, large screen LCDs are:

- (1) Developing new liquid crystals which "twist" or align themselves differently in response to ever smaller differences in the applied electric field;

- (2) Controlling or "addressing" the electric fields of very small points (pixels) arranged in large display areas.

Also, LCDs support sharper lines in that each picture element (pixel) functions digitally. LCDs do not suffer from the loss in contrast due to the gradual decrease in light at the edges of the phosphor.

LCDs do suffer from limitations that are less of a problem for CRTs. For example, LCDs possess serious viewing angle restrictions. Typically, LCDs have reduced contrast at viewing angles 40 degrees or more from a position directly in front of the screen. Also, viewing angle chromaticity shifts may occur and there may be reductions in light intensity. Current technological research is attempting to resolve these problems.

In terms of temporal performance, LCDs do not suffer as much from jitter since each pixel is defined by a specific location which is, therefore, geometrically stable and does not move from frame to frame (Committee on Vision Report, 1983, p. 95).

Like CRTs, LCDs are subject to flicker. Flicker occurs in response to repeated application of voltage to the crystals. However, the refresh rate required for LCDs is lower than that for CRTs.

LCDs suffer from fewer chromatic problems. Unlike CRTs, LCDs are better able to maintain color over a greater range of background brightness conditions.

2.4 ENVIRONMENTAL ASSUMPTIONS

Information transfer effectiveness between user and display is impacted by the environment within which the display is used. One factor known to influence visual sensitivity is the level of light adaptation of the eye. At medium and high levels of ambient illumination, the cone system of the retina dominates perceptual detection and discrimination. Since the pilot has available artificial sources of light, the assumption has been made that the pilot's eyes are always sufficiently light adapted to support the cone system. It should be noted, however, that in extreme cases, as when the pilot does not make use of these artificial light sources, or when the pilot's eyes are in the midst of light-adapting (which may take on the order of several minutes), sensitivity to retinal illumination, spectral composition, and spatial discrimination will be adversely affected.

The ability to detect small detail by means of the cone system is also dependent upon the position of the display relative to the visual system. Although the exact location of the electronic display in the cockpit has not yet been determined, it is expected that the user will be able to look directly at the screen using foveal rather than peripheral vision. Where this assumption is suspect is in situations where the pilot is actively searching for a piece of information on the display which is in an unknown location. Here peripheral vision may assist in directing one's gaze toward a sought after item. Considerations of visual search are discussed in Chapters 3 through 7 of this Handbook.

A few assumptions concerning the cockpit environment should be mentioned. This assumptions, which have guided the analyses described in this Handbook include:

- The distance from the instrument approach plate to the pilot's eyes is assumed to be approximately 75 cm.
- Vibration of both the display and the pilot is a frequent occurrence. How this affects visual performance is unclear and is an area in need of further research, but IAP chart designers should be aware that vibration will almost assuredly degrade performance at the extremes of detection and acuity to some degree. It is not possible to provide specific correction factors required for designing adequate paper or electronic displays that will be usable in spite of vibration. The IAP chart designer can only assume that visual performance degradation will occur and attempt to compensate by using display values that supersede those recommended for displays used under less strenuous environmental conditions. This means, for example, that critical information (e.g. approach name, inbound heading, minimum descent altitude) should be presented using larger type sizes.
- The pilot is assumed to be engaged in a multiple task situation. The consequences of multiple tasks for the design of chart displays is unclear. At the very least it is assumed that the pilot refers to the IAP chart briefly before moving on to other visual tasks. The multiple task situation means that the applicability of display standards intended for the office environment must be treated with caution. The office worker is assumed to use the display for substantial periods of time. Consequently, issues of prolonged display viewing are critical. The IAP chart user, in contrast, is assumed to use this display for brief periods of time. Instead of prolonged viewing, the IAP chart user must be able to quickly adapt his/her visual system to the conditions provided by the display. Comfortable viewing for long periods of time is not the objective. Rapid adaptation in support of brief looking at the display before shifting the eyes to some other viewing location is an important requirement, although its exact implications in terms of standards is not yet clear.
- The range of cockpit luminance conditions is likely to be large. Evaluation of display quality must address the problems that are likely to arise as a result of especially bright light striking the display surface.

The next three sections review display performance standards for paper, CRT, and LCD media. These standards have been derived, to the extent possible, to take into account the consequences of the environmental factors just described. Three types of standards are addressed: spatial, temporal, and chromatic.

2.5 SPATIAL VISION

This section reviews the display performance factors that affect spatial vision and the conditions that are required to support the ability of the visual system to adequately detect information presented on the screen. The most critical spatial vision variables are:

- Resolution
- Luminance

- Contrast
- Luminance Uniformity
- Contrast Polarity
- Convergence and Focus
- Symbol Alignment
- Anti-Aliasing and Shades of Gray
- Viewing Angle

2.5.1 Resolution (Paper, CRT, LCD)

The image quality of a display is usually associated with the resolution that can be supported by that display. Resolution directly impacts the sharpness and clarity of the displayed image in that it measures the number of individual pixels that can be selectively controlled or written. Resolution is usually measured in dots per inch (dpi) or dot density.

For a display with a given size, resolution would appear to be a function of two factors: the number of pixels that can be controlled and the size of those pixels. The first factor, number of pixels that can be controlled, is the limiting factor that determines the achievable screen resolution. For this reason, manufacturers typically specify the number of rows and columns of the screen. For example, common text editing displays have an array of pixels with 480 rows by 640 columns while entertainment color television is usually 480 rows by 320 columns.

In order to calculate the *pixel density* of an electronic display, the size of the screen (in inches) and the total number of pixels must be known. Dividing the number of pixels by the size of the screen produces the number of dots per inch. Current high resolution screens, either LCD or CRT, are typically in the range of 150 to 200 dots per inch in black and white. Paper media, in contrast, are usually 300 to 600 dots per inch. Pluche and Hansman (1990) argue that a resolution of 600 dots per inch does not significantly improve performance beyond that achieved with a 300 dot per inch resolution. If this conclusion is correct, existing LCD and CRT displays must improve their resolution by a factor of about two in order to achieve the resolution level used with existing IAP charts.

None of the reviewed standards provides a recommended value for screen resolution. The reason is likely to be that, given existing resolution capabilities, the recommendation is always to seek the greatest resolution possible at a reasonable cost. Rather than specifying minimum resolution performance standards, it is probably more important to emphasize the consequences of using a display that does not have the resolution of current IAP paper charts. The implication is that electronic displays will be unable to simply reproduce existing paper charts. Compensation for the lower resolution levels will require the use of larger characters and symbols, the obvious consequence being that not all of the information currently presented on a paper chart will be able to appear on a single electronic screen.

Resolution on CRT or LCD screens should be as high as achievable for electronic media up the standard used for paper. For the unaided observer, the critical test is whether the sizes of alphanumeric characters and symbols that are actually used is sufficient to compensate for the lower resolution level available for the selected displays. For paper, an effective resolution of 300 dpi (print quality of 600 dpi) has proven to be acceptable.

2.5.2 Luminance (CRT, LCD)

Display quality is also impacted by the mean luminance of the screen, the perceptual correlate of which is perceived brightness. Luminance has its strongest influence on the ability of the visual system to detect the detailed information required to differentiate alphanumeric characters and symbols. Insufficient luminance levels must be compensated for by increasing the size of small objects.

Luminance levels must also take into account the background lighting provided by the environment in which the display is used. In a dark environment, a screen with high mean luminance will dominate the visual scene and cause other devices to be masked out. One reason for this is the effect the bright light from the screen has in influencing the light adaptation of the eye. If the eye adapts to the bright light of the screen, its adaptation level with respect to the background environment will be incorrect. It is also possible for a screen to be so bright that it impairs the identification of characters on its own surface.

A screen with insufficient mean luminance will be unreadable in high ambient illumination. In the cockpit environment, where ambient illumination can reach 100,000 lux, the bright ambient light can "wash out" the screen, especially when CRTs are used.

One solution to this problem is to use displays which are capable of adjusting their mean luminance in response to changing cockpit illumination. Even if automatic luminance control is provided, however, manual control of screen brightness should be available to the user. This requirement for manual luminance control is recommended by all of the aviation standards that were reviewed (see Table 2-1).

The recommendation for manual control over luminance levels does not specify the range of luminance levels that should be supported by the display. Tables 2-2 and 2-3 list the recommended luminance ranges derived from the aviation and office standards. The office standards should be used with great care in that the range of luminance conditions found in the office environment is much less extreme than that of the cockpit environment.

Tables 2-2 and 2-3 show that the majority of standards recommend that the luminance level be "sufficient." Only rarely is the range of desired luminance values specified. However, one document has suggested that the screen brightness for a cockpit CRT must range from 0.1 - 200 fL to meet military specifications (Pluche & Hansman, 1990).

Although specific maximum and minimum luminance values are recommended in ARP 1874, it is important to note that this range of values refers to luminance levels for each pure color displayed (e.g. red, green, and blue) and, therefore, is only applicable to color CRTs. The maximum luminance levels recommended are as follows:

Table 2-1. Aerospace recommendations reviewed for CRTs

ARINC = Aeronautical Radio, Inc. ARP = Aerospace Recommended Practice AS = Aerospace Standard MIL-STD = Military Standard	
ARINC 725-1	Electronic Flight Instruments (EFI)
ARP 1874	Design Objectives for CRT Displays for Part 25 (Transport) Aircraft
ARP 4032	Human Engineering Considerations in the Application of Color to Electronic Aircraft Displays
ARP 4102	Flight Deck Panels, Controls, and Displays
ARP 4102/7	Electronic Displays
ARP 4155	Human Interface Design Methodology for Integrated Display Symbolology
AS 8034	Minimum Performance Standard for Airborne Multipurpose Electronic Displays
MIL-STD-1472D (CRT Section)	Human Engineering Design Criteria for Military Systems, Equipment and Facilities

Symbol Lines

Red 48 cd/m² (14 fL)
 Green 103 cd/m² (30 fL)
 Blue 17 cd/m² (5 fL)

Area Subjects

9.3 cd/m² (2.7 fL)
 20 cd/m² (5.8 fL)
 3.9 cd/m² (1.15 fL)

Based on 0.67 mm line width.

Minimum luminance levels are:

Symbol Lines

Red 0.192 cd/m² (0.056 fL)
 Green 0.420 cd/m² (0.120 fL)
 Blue 0.068 cd/m² (0.024 fL)

Area Subjects

0.113 cd/m² (0.033 fL)
 0.247 cd/m² (0.072 fL)
 0.041 cd/m² (0.012 fL)

**Table 2-2. Recommendations for mean luminance values for
VDT workstations.**

Source	Mean Luminance	Conditions/Comments
Gorrell (1980)	85 cd/m ²	
Snyder & Maddox (1978)	65 cd/m ²	
Cakir et al. (1980)	45 cd/m ² minimum	80-160 cd/m ² preferred
ANSI/HFS Standard (1988)	≥ 35 cd/m ²	
IBM (1984)	35 cd/m ²	for character sizes of 16 min of arc
Shurtleff (1980)	10 ft L.	

Manual controls, either in conjunction with or independent of automatic controls, should be made available to the user to vary mean screen luminance. The appropriate screen luminance range will be dependent upon the contrast ratio and size of displayed symbology, hence a minimum value cannot be specified. However, a range of 0.1 to 200 fL has been suggested. For the unaided observer, the range of available luminance levels should be sufficient to handle the range of ambient lighting conditions likely to be found in the cockpit environment. Sufficient luminance and/or chromatic difference should always be available to support discrimination between all symbols, characters, and backgrounds.

ARP 1782 describes the photometric techniques for determining screen luminance levels. Visual conditions for evaluating luminance levels are described in Advisory Circular 25-11. Displays should be evaluated under four lighting conditions:

- Direct sunlight which reaches the display through a side cockpit window.
- Sunlight coming through a front window which illuminates a white shirt, then reflects onto the display.

Table 2-3. Aerospace recommendations for screen mean luminance.

Source	Recommended Mean Luminance
ARINC 725-1	Display symbology should be clearly readable under all ambient lighting levels ranging from night time conditions up to and including an illumination of 86,400 lux...
ARP 1874	Shall be sufficient to provide a comfortable level of viewing with rapid adaptation when transitioning from looking outside cockpit.
ARP 4102	The information shall be presented with the accuracy, legibility, and readability required for error-free control of the aircraft in all normal and abnormal flight situations.
ARP 4102/7	Shall not cause eye strain; shall be legible under all lighting conditions
AS 8034	Shall be sufficient to provide a usable display under the maximum ambient illumination level; Shall be sufficient for the display to perform its intended function.
MIL-STD-1472D	The ambient illuminance shall not contribute more than 25% of screen brightness through diffuse reflection and phosphor excitation. A control shall be provided to vary the CRT luminance from 10% of minimum ambient luminance to full CRT luminance.

- Sunlight above the horizon in front of the airplane and above a cloud deck which reaches the pilot's eyes. This situation, because of its frequency and duration of occurrence, is considered the most critically in need of evaluation.
- Night or dark lighting conditions which require the brightness levels of the display to be sufficiently adjustable (i.e. can be dimmed) to ensure that outside vision is not inhibited.

2.5.3 Luminance Contrast and Contrast Ratio (Paper, CRT, LCD)

2.5.3.1 ELECTRONIC DISPLAYS

Resolution and luminance both affect the ability of the visual system to detect small detail. A third factor is luminance contrast, the brightness contrast between characters or symbols on a display and the background against which those items appear.

Although a number of measures of contrast have been used, contrast ratio, expressed as a ratio such as 10:1, is probably the most commonly used:

$$\text{Contrast Ratio} = \frac{L_{\max}}{L_{\min}} = L_{\max} : L_{\min}$$

Luminance differences are not the only possible source of contrast. The human visual system is also sensitive to chromaticity (or color) differences. Luminance and chromaticity differences are independent factors that may be used alone or in combination to differentiate symbols from their background. For example, a triangle on a colored screen will be undetected if it is equal in brightness *and* color with the background. However, by varying either of these dimensions, identification of the symbol becomes possible. Chromaticity differences will be discussed in Section 2.7. This section focuses on luminance differences.

The amount of luminance contrast needed for error-free performance is a function of a number of parameters. Among these are symbol size, reflected illumination, and the training and biases of the observer. Given the large number of influencing factors, specification of a minimum luminance contrast ratio for all flight situations is not possible. Table 2-4 lists the recommended performance standards for displays intended for use in the aviation environment. Characteristic of these recommendations is their lack of specificity. It is likely that specific recommendations have not been made for a number of reasons, including the increased costs of errors associated with reading aircraft displays and the range of environmental conditions likely to be found in the cockpit.

The recommended contrast ratios for CRTs used in the office environment are presented in Table 2-5. Although actual ratios are provided, the range of values does not provide substantially greater guidance information. Since it is probably wise to be conservative, and because this is not a difficult level for current technologies to reach, a minimum contrast ratio of 20:1 for direct viewing and 10:1 for any other eye position would appear to be suitable in ambient lighting conditions ranging from 0.1 to 8000 lumens/ft². For segmented displays with activated segments, the activated segments should have a contrast ratio with the immediate background of 2:1. For unactivated segments, there should be no greater than 1.151 (Green, 1992).

For CRTs and LCDs, a minimum luminance contrast ratio of 20:1 for direct viewing and 10:1 for all other viewing situations is desirable. For segmented displays, the contrast ratio should be 2:1 for activated segments and 1.15:1 for unactivated segments. For the unaided observer, the display should be evaluated under a range of cockpit environment conditions to ensure that sufficient luminance contrast is always possible.

Table 2-4. Aerospace recommendations regarding luminance contrast.

Source	Contrast Ratio	Comments/Conditions
ARP 1874	Displayed symbology shall be distinguished from its background from other symbols by means of luminance differences or chromaticity differences, or both, in all ambient conditions defined (by ARP 1874).	
ARP 4102	The information shall be presented with the accuracy, legibility, and readability required for error-free control of the aircraft in all normal and abnormal flight situations.	
ARP 4102/7	Shall be legible under all lighting conditions.	
AS 8034	In all cases the luminance contrast and/or color differences between all symbols, characters, lines, or all backgrounds shall be sufficient to preclude confusion or ambiguity...	
MIL-STD-1472D	Contrast adjustment shall not be included in flight deck displays because they are disallowed by FAA regulations.	

There are several procedures for measuring electronic display luminance and contrast. One method is to turn the display off, measure the luminance, then measure a large area of the screen with all of the pixels turned on. This is an extreme measure and there are optical and electronic reasons that suggest this approach may not provide the actual luminance levels appropriate for defining symbol/background contrast (IBM, 1984). The technical literature suggests that a more appropriate measure may be to display several alphanumeric characters (for example, several "W"s). The background value is measured from the center of the non-illuminated area between the vertical strokes of adjacent "W"s. The high contrast value is then measured from the center of the illuminated stroke of one of the capital "W"s. Typically, the contrast ratio obtained in this manner is much smaller than the value obtained by large area measurements. However, this second approach better represents the actual contrast used by the eye to detect the separation between characters (IBM, 1984).

Table 2-5. VDT recommendations for luminance contrast values.

Source	Contrast Ratio	Conditions/Comments
Gorrell (1980)	$\geq 4:1$	
German Safety Standards	3:1 to 15:1	6:1 to 10:1 preferred
Deutsches Institut fur Normungen (1982)	3:1 to 15:1	6:1 to 10:1 preferred
Snyder & Maddox (1978)	$\geq 3:1$	$>15:1$ preferred
Cakir et al. (1980)	$\geq 3:1$	8:1 to 10:1 optimum
ANSI Human Factors Standard (1988)	3:1	7:1 preferred; accurate for character sizes from 10 to 20 min. of arc
IBM (1984)	3:1	15:1 preferred; accurate for character sizes of 16 min of arc
Shurtleff (1980)	18:1	in certain situations can be as low as 2:1

Because of the substantial differences in contrast ratio value that can be obtained, depending upon the measurement approach used, care must be taken in accepting a manufacturer's claims about contrast ratio and luminance values. ARP 1782 should be consulted before conducting photometric measurements of contrast or contrast ratio.

2.5.3.2 PAPER DISPLAYS

A recommended minimum contrast ratio standard for paper approach plates is difficult to obtain. The Fifth Edition (1990) of the Low Altitude Instrument Approach Procedures (IACC No. 4) states that "All symbols shall be printed in black, primary information shall be a solid color, and secondary information shall be screened in a 120 line / 15% of color format." The specific nature of this recommendation obscures the fact that it does not specify a minimum contrast ratio. Different inks on different types of paper will result in different contrast ratios even if these specifications are followed. Of some help is the fact that IACC No. 4 does indicate which pieces of information are to have relatively less contrast. This is accomplished by specifying varying screen percentages (e.g. 120 line/15%, 120 line/45%, etc.).

In contrast to these recommendations, the Eighth Edition (July, 1985) of the International Standards and Recommended Practices for Aeronautical Charts (Annex 4), developed by the Interna-

tional Civil Aviation Organization, states that "Colours or tints and type size used shall be such that the chart can be easily read and interpreted by the pilot in varying conditions of natural and artificial light" (p. 5). This general comment is not supplemented by additional detail in the rest of the document.

Because these documents are not specific with regard to a minimum contrast ratio necessary for paper presented instrument approach procedure charts, only a very general conclusion can be reached.

For paper displays, IAP charts should be printed with sufficient contrast between the characters and their background that they are easily read in all viewing situations.

2.5.4 Luminance Uniformity (CRT, LCD)

Luminance uniformity or its converse, luminance *non*-uniformity, can refer to two, somewhat different aspects of electronic displays. Large area non-uniformity is the gradual change in luminance or color from one area of the display to another (Snyder, 1980). Small area non-uniformity refers to the lack of consistency in color or luminance of adjacently written areas (e.g. the area across one arm of the letter "E"). Although there is little performance-related data available on either of these issues, recommendations have been made concerning acceptable large area non-uniformities (see Tables 2-6 and 2-7). Because there is no obvious reason to suspect that effects of luminance uniformity will be different for LCD versus CRT displays, the CRT literature will be considered applicable to LCDs.

The standards listed in Tables 2-6 and 2-7 are reasonably consistent in their recommendation that variation should be no greater than 20%. However, additional research is needed in this area.

Table 2-6. Aerospace recommendations for acceptable large area non-uniformities.

Source	Luminance Uniformity	Comments/Conditions
ARINC 725-1	vary <20%; no random flare-ups	
MIL-STD-1472D	ratio of standard deviation to mean luminance shall not be more 0.25	
AS 8034	<30% within useful display area, or <20% within central 80% of useful display area	

Table 2-7. VDT recommendations for acceptable large area non-uniformities.

Source	Luminance Uniformity	Comments/Conditions
ANSI Human Factors Standard (1988)	$\{ (L_{\text{point } x} - L_{\text{center}}) / L_{\text{center}} \} < 0.5;$ or vary $\leq 50\%$	see document (p. 67) for locations of point x
Snyder (1980)	vary $\leq 20\%$	value given for 4

With regard to small area non-uniformities, two of the reviewed documents have specific recommendations. ARP 1874 recommends that "Symbol lines of a specified color and luminance shall be uniform in width to (within) 0.35 milliradians over the useful screen" (p. 5). This recommendation is specifically for line width uniformity. From the VDT literature, the American National Standards Institute (1988) recommends that "Unintended luminance variations, within half a degree of arc, calculated from the design viewing distance anywhere on the display, shall be less than 50 percent" (p. 25) [bold in original].

For the unaided observer, non-uniformities in brightness or color on CRT or LCD displays shall not be present. When varying the luminance of the display from minimum to maximum, the relative luminance of all characters, symbols, and backgrounds should be visually constant. Employing photometric techniques, a large area non-uniformity of less than 20% is acceptable. For luminance variations within half a degree of arc, 50% or less is acceptable.

See ARP 1782 for a discussion of photometric techniques for determining luminance uniformity.

2.5.5 Contrast Direction/Contrast Polarity (Paper, CRT, LCD)

2.5.5.1 ELECTRONIC DISPLAYS

Contrast direction and contrast polarity refer to the direction of the luminance difference between the symbol and its background. A screen having a dark image (symbol) on a bright background is referred to as having a *positive polarity* or *negative contrast*. The reverse (bright image on a dark background) is termed *negative polarity* or *positive contrast*. The literature is not consistent as to whether positive or negative contrast is preferred (IBM, 1984; Committee on Vision Report, 1983). For example, "CRT displays on which dark characters are presented on a light background appear to minimize the effect of reflections on the VDT user's screen, but such displays may require a higher refresh rate in order not to appear to flicker" (American National Institute for Standards, 1988).

This statement is suggestive of one reason why a consistent recommendation has not been made. Polarity is impacted by a number of factors, including glare, flicker, background luminance, and user's light adaptation level. If positive polarity is used, its brightness level should not be so high as to wash out surrounding displays/surfaces, or to impact the light-adaptation level of the user. Consequently, decisions as to polarity must consider the performance level of the display (can the greater likelihood of flicker occurring be controlled) and the general lighting conditions of the cockpit.

Only one of the reviewed aerospace documents provides a specific recommendation concerning contrast direction/polarity. MIL-STD-1472D specified that "Pictorial or situation data such as plan position indicator data, shall be presented as luminous symbols/dark background" (Section 5.2.4.9). This recommendation may be interpreted to mean that IAP charts should be displayed with dark backgrounds. It is not clear, however, that this conclusion is adequately supported. In fact, some researchers of aviation charts (e.g. Taylor & Hopkin, 1975) clearly recommend the use of positive polarity because of the specific requirements such charts have to present legible symbols and to code land surface heights. The VDT literature, in contrast, appears to be far from unequivocal on the issue (see Table 2-8).

Because of the potential need to represent land surface heights and other continuous forms of information, a recommendation is made here to use positive polarity. This recommendation is based, however, on the assumption that those factors negatively impacted by the use of positive polarity, such as flicker, can be adequately handled.

For CRT and LCD formats, positive polarity is probably preferred because of the unique information format requirements of IAP charts.

2.5.5.2 PAPER DISPLAYS

With regard to the paper presentation of IAP charts, both common practice and the relevant national standards specify that contrast direction should be dark (black) symbols on a light background.

Contrast direction, on paper, should be dark symbols on a light background.

2.5.6 Convergence and Focus (CRT)

ARP 1874 and AS 8034 state that lines, symbols, and characters should have no tails, squiggles, skews, gaps or bright spots. Also, the color of a line or symbol should always be obvious. In essence, this means that characters and symbols should possess high symbol quality. Symbol quality can be a problem for CRTs because of the use of electron guns for writing images on the screen. Improper focusing of the electron gun can cause blurring. If several electron guns are used with a patterned screen, blurring can result if the electron guns do not properly converge. Descriptions of photometric techniques for measuring misconvergence and geometric distortion are provided in ARP 1782.

Table 2-8. VDT Recommendations for Contrast Direction/Polarity

Source	Contrast Direction/Polarity	Comments/Conditions
Shurtleff (1980)	Either	Should have manual control of polarity.
Rey & Meyer (1977)	Negative contrast preferred	Negative contrast equals dark symbol on bright background
German Safety Standards (1980)	Negative contrast preferred	
IBM (1984)	Either	
Cakir, Reuter, von Schmude & Armbruster (1978)	Negative contrast preferred	

For the unaided observer, geometric distortion and misconvergence can be assessed by noting significant blurring of displayed symbology. This evaluation process should include filling the screen with characters in order to evaluate all parts of the screen. W's and M's are especially good for this purpose because they are large letters that fill the entire character space. Use of a variety of different symbols and fonts during the evaluation process should provide sufficient conditions for assessing convergence and focus. Table 2-9 suggests that misconvergence, when assessed by photometric measurement, should be no greater than approximately .7 milliradians.

For the unaided observer, lines, symbols, and characters should have no tails, squiggles, skews, gaps or bright spots. Line color should be obvious. Employing photometric measurements, misconvergence should not be greater than 0.7 milliradians.

2.5.7 Symbol Alignment (CRT, LCD)

Some of the information in IAP charts is presented in tabular form. In other cases, information must be aligned with the correct label. Display media may differ with respect to how accurately symbols are aligned relative to each other. Table 2-10 presents the aerospace recommendations for symbol alignment. There is general consensus that alignment of symbols, both horizontally and vertically, should be within 0.2 inches. If photometric tools are not available, the display can be evaluated by filling the screen with characters, such as M's or W's, and assessing their apparent alignment.

Table 2-9. Aerospace recommendations for convergence.

Source	Convergence	Conditions/Comments
ARINC 725-1	The centers of any two of the primary color lines which produce a composite color line should be converged within 0.018 inches (.5mm) throughout the entire display area over the full dimming range.	
ARP 1874	Width of any misconverged portion shall be no larger than the width of the desired color. Typically... should be within 0.55 mr within the central 80% of the screen and 0.7 mr over the entire screen from any point within viewing envelope.	
AS 8034	(When a multiple gun or beam penetration CRT...) convergence shall be within the average of the line widths. (When a raster generated symbology...) convergence shall be within one display line width or 0.7 milliradians, whichever is greater.	

To the unaided observer of a CRT or LCD, symbols which should be aligned either horizontally or vertically should appear so aligned. Employing photometric techniques, symbol alignment should be within 0.2 inches.

2.5.3 Defects and Line Failures (CRT)

LCDs are subject to failures of individual elements, resulting in the element remaining always "on" or "off." Similarly, single or multiple row or column line failure can occur. At this time, no standards exist to define minimum failure standards. However, any defects that might occur should not be distracting or cause misreading of information presented on the display (Green, 1992). Row or column failures should be an improbable occurrence.

Any defects in the display should not be distracting or cause information misreading. Row or column failures should be improbable occurrences.

Table 2-10. Aerospace recommendations for symbol alignment.

Source	Symbol Alignment	Conditions/Comments
ARINC 725-1	The error in position in accuracy of one symbol with relation to another one should not be more than 0.02 in (.5 mm).	
ARP 1874	Shall be aligned at their midpoints to within 0.7 mr from any point within the instrument's viewing envelope.	At viewing distance of 28 inches equals 0.02 inch
AS 8034	Symbols which are interpreted relative to each other... shall be aligned, including parallax effects throughout the design eye viewing envelope, to preclude misinterpretation of information.	

2.5.9 Anti-Aliasing and Shades of Gray (CRT, LCD)

Two critical parameters for representing high information density on a display medium are anti-aliasing and shades of gray. Aliasing refers to the stair-step effect that can appear when diagonal lines are portrayed on an electronic display. This effect occurs because when a pixel must be either completely on or completely off. Anti-aliasing techniques are used to smooth out diagonal lines.

For CRT's, aliasing is less noticeable because of phosphor smoothing, the overlap of emitted light from each phosphor because of their Gaussian distribution (see Section 2.3.2). For current LCDs, however, aliasing is much more problematic because of the uniform distribution of light emitted by each pixel surface (Pluche & Hansman, 1990). Future LCDs may combat this problem by lighting up parts of a pixel.

Although there are no accepted standards for the aliasing problem, display evaluation should include visual inspection of diagonal lines to ensure that the display will be capable of clearly presenting lines in a variety of different orientations.

Lines and characters presented on CRTs or LCDs should appear smoothly written and contain no unwanted jagged edges. Special attention should be paid to angled lines drawn on LCDs, which are the most difficult to anti-alias.

Current instrument approach charts are printed with three shades of gray. Transfer of IAP charts from the paper to electronic media may require the capability to present shades of gray on

electronic displays. Pluche and Hansman (1990) describe three methods for generating gray shades to be on electronic displays:

1. Spatially, where resolution lines are combined to give different gray shades.
2. Sequentially, where refresh rates are combined to give different gray shades.
3. Excitationally, where the emission is in proportion to the excitation modulation like in the CRT. The modulation can be achieved by either pulse width, or amplitude, or a combination in the excitation signal.

Current aerospace recommendations do not specify a minimum gray scale capability for electronic flight deck displays. However, 15 gray levels are generally assumed to be necessary to minimize antialiasing and chromatic distortions.

A minimum of 15 gray levels is likely to be required for near-term IAP chart electronic displays.

2.5.10 Viewing Angle (CRT, LCD)

Viewing angle, as a contributor to display quality, refers to the legibility of displayed symbology when the screen or page is examined from an angle other than perpendicular to its face. Because the orientation of a page can be readily modified, viewing angle is not an important factor for paper displays. Viewing angle is a much more serious consideration for electronic displays.

The limit of the viewing angle for a particular electronic display is usually described as the point at which the contrast ratio reaches a predetermined lower limit (Pluche & Hansman, 1990). Care must be taken that the manufacturer's acceptable minimum contrast ratio meets or exceeds the certifier's minimum.

With regard to a minimum viewing angle requirement for flight deck displays ARINC 725-1 is the most specific (see Table 2-11). A left/right viewing angle of 53/53 degrees and an above/below viewing angle of 35/0 degrees appears to be sufficient, depending on the location of the electronic IAP relative to the user. If the electronic IAP chart is to be incorporated into the primary Electronic Flight Instrument System (EFIS), these angles are probably adequate. Placement in other locations, however, might require extreme viewing angles in one direction or another. In addition, simultaneous viewing by other crew members may require further modifications of viewing angle minimums.

At present, LCDs have the greatest difficulty in meeting viewing angle requirements. Special attention, therefore, should be paid to viewing angle when assessing the adequacy of any LCD IAP display.

Table 2-11. Aerospace recommendations for viewing angle.

Source	Viewing Angle	Conditions/Comments
ARINC 725-1	Should be designed for a minimum viewing angle, from the normal line, of 53 deg left, 53 deg right, 35 deg above, and 0 deg below.	
ARP 1874	Shall be completely visible from any eye position within the instrument's viewing envelope as specified by the equipment manufacturer.	
AS 8034	Shall have a sufficient viewing angle to provide complete visibility of the displayed information from any viewing position within the specified design eye viewing envelope.	

Current aerospace recommendations require a viewing angle of 53 degrees in the left and right direction, 35 degrees above, and 0 degrees below a plane perpendicular to the screen face. However, display location and additional crew member viewing may require different specifications. Special attention should be paid to the viewing angle characteristics of any proposed LCD IAP chart.

2.6 TEMPORAL VISION

The perception of change takes place through detection of changes in the light over time. These changes are most common when they occur as a result of an event, such as the movement of an object. IAP charts embodied on electronic displays in the near-term are expected to provide static representations of navigational information. Consequently, it would appear that temporal vision is not an issue.

However, IAP charts presented on electronic displays will have temporal instabilities that must be considered. Two types of temporal instabilities must be considered, flicker and jitter.

2.6.1 Flicker and Refresh Rate (CRT, LCD)

Flicker refers to variation in luminance over time that occurs as a result of constant rewriting of the image on the screen to prevent the image from degrading. Flicker on CRTs arises as a consequence of two factors: the decay rate of the phosphors used to form a symbol or character, and the rate at which the electron beam reactivates the phosphors. If the refresh rate is too slow the

Table 2-12. Aerospace recommendations for refresh rate and flicker.

Source	Refresh Rate	Comments/Conditions
ARINC 725-1	> 50 Hz for stroke written display; 40/80 ² for 2:1 interlace raster scan	
ARP 4102/7	Shall not cause eye strain or other undesirable physiological effects	
ARP 1874	Since a subjective phenomenon, criteria cannot be "no flicker"; should be barely discernible day or night considering foveal and full peripheral vision and a format most susceptible to producing flicker	Flicker is determined by refresh rate, phosphor persistence and the method of generating mixed colors
AS 8034	Shall not exhibit an unacceptable level of flicker	For the full range of ambient environment lighting
MIL STD 1472D	Maximum possible "consistent with the user's information handling rates"	For graphic displays

² frames per second/fields per second

image will appear to flicker or blink. Flicker on LCDs occurs as a result of the repeated application of voltage to the pixels.

Flicker can affect the display user in two ways. In some cases, it can actually be seen as a very rapid blinking of the characters and symbols displayed on the screen, which can be distracting to the user. Even if it is not actually seen, flicker can cause eye strain and other forms of visual discomfort. Flight crews may be less subject to problems such as eye strain because they typically do not stare at display screens for long periods of time. However, the broad range of illumination conditions may make the problem of flicker more difficult. Also, flicker can reduce visual acuity and hinder the process of eye accommodation required to read the screen.

Flicker sensitivity is a function of several factors:

- Size of the area: Flicker will be seen more quickly in a large area than a small area.

Table 2-13. VDT recommendations for refresh rate and flicker.

Source	Refresh Rate	Comments/Conditions
Cakir, Hart & Stewart (1980)	25/50 or 30/60 ²	
Michel (1983)	50 - 60 Hz	Dependent upon lighting conditions
Gorrell (1980)	60/60 ²	
Reading (1978)	25/50 or 30/60 ²	
IBM (1984)	50 Hz	40 Hz with interlace technique depending upon brightness
Bylander (1979)	50 - 60 Hz	
Sherr (1979)	50 - 60 Hz	
ANSI/HFS (1988)	Flicker free	Should be empirically demonstrable
Deutsche Institut fur Normungen (1982)	25 frames per sec/50 Hz for positive contrast	Higher for negative contrast
German Safety Standards (1980)	Flicker free	

² frames per second/fields per second

- Brightness of the screen: The brighter the screen, the more susceptible will that display be to flicker. An important implication is that positive polarity displays (dark characters on a light background) will be more susceptible to flicker. Also, the high ambient lighting conditions that can be found in the cockpit increase the likelihood that flicker will be seen.

Tables 2-12 and 2-13 present the compiled recommendations from the aerospace and VDT literature.

Table 2-14. Aerospace recommendations for allowable jitter (for CRTs).

Source	Allowable Jitter	Conditions/Comments
ARINC 725-1	0.2 millimeters peak-to-peak	
ARP 1874	≤ 0.3 milliradians peak-to-peak	Anywhere within viewing envelope
AS 8034	≤ 0.6 milliradians	

Given these values it appears that for CRTs a refresh rate of 50 to 60 Hz is appropriate. For LCDs a lower refresh rate is usually acceptable, and minimum frame rate of 30 Hz has been recommended (Pluche & Hansman, 1990). Because of the unique environmental conditions of the cockpit, these rates should be treated as minimum performance levels that should be visually evaluated under realistic flight conditions. This evaluation process involves staring at the screen at a normal viewing angle and using peripheral vision, which is especially sensitive to motion, to detect any variations in the appearance of the screen.

For the unaided observer of a CRT or LCD, there should be no undesired rapid temporal variation in display luminance for a symbol or display field. For CRTs, a refresh rate of 50 - 60 Hz is generally acceptable. For LCDs, a frame rate of 30 Hz may be acceptable.

2.6.2 Jitter (CRT, LCD)

The second temporal consideration is jitter. Jitter can occur on raster-written CRTs when there is a slight displacement in the dot locations of a character as it is rewritten each cycle. The perception of jitter is influenced by the frequency and spatial displacement of the image. For example, at those frequencies to which the visual system is most sensitive (about 1 to 3 Hz), a displacement of 10 arcseconds or more will be perceived as jitter. Jitter frequencies above 25 Hz are usually seen as image blurring rather than jitter (IBM, 1984).

Jitter is typically not a factor in LCD displays since each pixel has a fixed position. However, the processing algorithm that determines which pixels light up during each frame may cause a slight jittering effect for specific characters, especially when anti-aliasing is involved. Unfortunately, no data is available with regard to acceptable jitter limits for LCDs.

Table 2-14 displays the aerospace recommendations for jitter. For CRTs, it is not apparent that any strong conclusion can be reached given the range of values shown in this table. Given that jitter may be compounded by the levels of vibration found in the cockpit environment, the most restrictive performance level, 0.3 milliradians peak-to-peak, will be recommended. Again, visual

evaluation should be performed by staring at a screen filled with characters, and using peripheral vision to assess whether jitter is detectable.

For the unaided observer, a static CRT or LCD display should contain no discernible jitter. Employing photometric techniques, image jitter should be within 0.3 milliradians peak-to-peak.

2.7 CHROMATIC VISION (CRT, LCD)

Some of the factors that affect the perception of color were described in Section 2.2. This review emphasizes the importance of a number of factors, such as ambient light level, on our perception of color. The underlying point is that color perception is not absolute, which complicates the attempt to select colors that will always be detectable under normal cockpit conditions.

In order to specify colors for display use, it is important to use a system that accurately describes each color. The CIE color system, shown in Figure 2-1, was developed to serve this role. Although there is some variation due to individual differences in the perception of color, the CIE established in 1931 a standard normal observer which defines a function relating the spectral composition of a light and its "normally" perceived color. (For an excellent discussion of the CIE color system, see Boff & Lincoln, 1988).

The original CIE color system and its later revisions provide a metric that allows researchers to determine objectively the colors produced by different equipment in different laboratories. In the CIE system, all colors may be mapped into a two-dimensional space, for example x and y . Each monochromatic color (comprised of a single wavelength) defines a point along the U-shaped outer boundary. Points along a line towards the middle reflect colors with less purity (saturation) until they reach the middle region which represents white.

Data on chromatic discrimination may be mapped onto the CIE 1931 chromaticity diagram as shown in Figure 2-1. Lines along the outer boundary represent equal steps in subjectively perceived color (dominant wavelength). Lines toward the middle represent equal jumps in color purity. As can be seen, equal distances in the CIE color space do not represent equal steps in perceived color. Figure 2-2 diagrams subjectively-equal color spaces where the ellipses represent the boundaries of the just noticeable differences. As shown in this figure, discriminability is greatest in the extreme blue and red ends of the spectrum (the extreme low and high wavelengths, respectively), whereas discrimination is relatively poor in the green, blue-green, and yellow-green regions (Snyder, 1980). The implication of these results is that colors designed to maximize separation in a CIE color space will not necessarily maximize perceptible separation. Therefore, it is not possible to ensure, a priori, that electronically generated colors will be easily discriminable in all viewing situations. Display designers must be careful to determine that adequate simulation testing has been done on any proposed color set.

Other factors that impact color selection include:

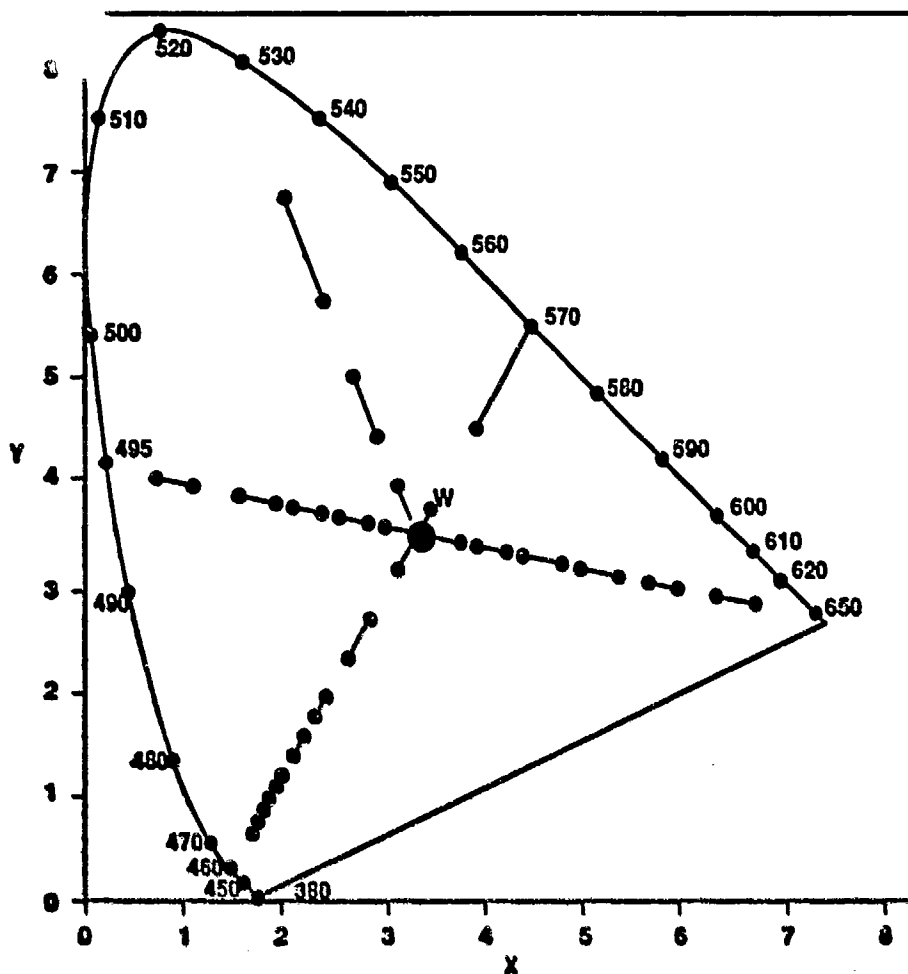


Figure 2-1. The CIE color system.

- Chromatic differences are more difficult to detect when applied to very small objects. The application of color to symbols should ensure that the colors used are maximally discriminable.
- The normal eye is blue-blind in the central fovea which means that pure blue is especially difficult to see;
- Some common forms of color deficiency require that colors differ in the amount of blue present as well as red-green in order to be distinguished, hence suggesting that blue be used as a component color of most symbology; and
- Because of chromatic aberration in the eye, displays using extreme red or blue may create a three-dimensional effect, thus requiring that their use be used with caution and adequately tested for influences on pilot performance.

It is important to note that current color generation techniques for electronic displays sometimes result in reduced resolution or addressable pixels per inch (Pluche & Hansman, 1990). Certifiers

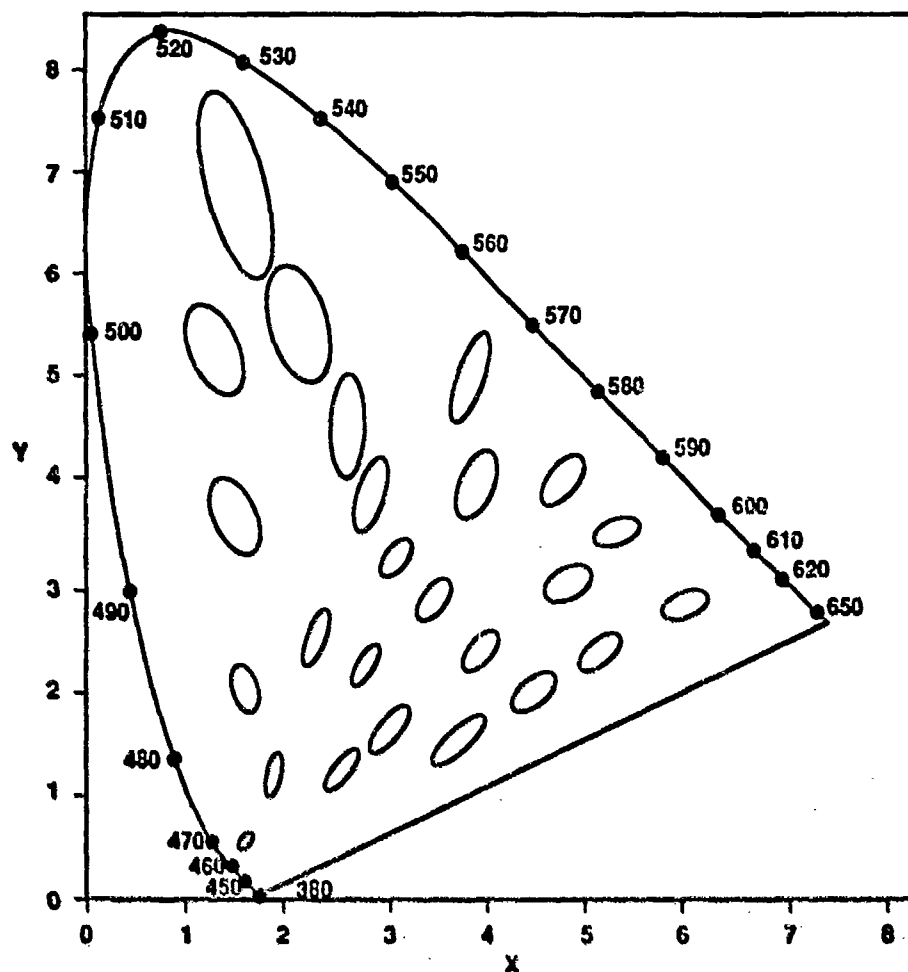


Figure 2-2. Use of the CIE color system for mapping discriminable colors.

of electronic IAP charts must be aware that adding color to a display may possibly degrade overall safety and performance if not tested adequately. Some considerations to keep in mind are:

- Approximately 1% of Class I pilots have obtained medical waivers for color vision. More importantly, some of the tests used to pilot color vision are designed to pass individuals with mild to moderate color deficiencies. Therefore, a wide variability in performance in color vision discriminability is present in certified pilots (ARP 4032).
- Each type of display technology has its own unique problem for adequately representing color in the cockpit. For CRTs there is significant washout of colors at high ambient illumination levels. For LCDs there are chromaticity shifts at off-axis viewing angles. Generating adequate color for all possible viewing situations is still a technological problem in the short term.

- Although enhancement of performance through the use of color has been demonstrated for a wide variety of activities and settings, no systematic controlled studies have shown that using color has similar effects for pilots using IAP charts.

These considerations plus others, make it difficult to state with confidence specific recommendations for the use of color in electronic IAP charts. With this in mind the following conclusion is provided.

Any use of color in electronic IAP charts should be adequately tested in flight situations with a representative sample of pilots. As a guideline for the design of such devices, ARP 4032 should be consulted.

It is also important to ensure that chromaticity uniformity is preserved. AS 8034 specifies that the chromaticity difference between any two points of the same color located at any position on the screen should not be sufficient to cause erroneous interpretation of that information. This is especially critical if color coding is used.

There should be sufficient chromaticity uniformity to ensure adequate interpretation of information.

Additional guidance on the use of color is provided in the remaining chapters of this Handbook.

2.8 TABLE OF CONCLUSIONS AND SUMMARY

Table 2-15 presents a quick reference summary of the conclusions and recommendations described in this chapter. As was mentioned in the beginning of this chapter, two types of conclusions are usually presented: One version for the unaided observer and a second more specific recommendation which assumes the viewer has access either to the manufacturer's specifications or appropriate equipment for conducting photometric measurements. ARP 1782 should be consulted for conducting such measurements.

Some final comments need to be made about these guidelines. For a number of reasons, these guidelines should not be treated as absolute values that must be met. Tradeoffs often must be made since achievement of one requirement may occur at the expense of other requirements. In addition, the standards that have been used to derive display performance values are not oriented towards the specific situation of the IAP chart. Consequently, it is essential that judgment be used in applying them to the case of IAP charts. Also, many of the recommendations described here are not based on the type of experimental foundation that is usually desired. In many cases, practical experience and judgment has been used in place of missing experimental data. Finally, and perhaps most importantly, the research and theory on how the visual system works is not sufficient to close the gap between basic and applied research.

In spite of these limitations, the data provided in this chapter represents current thinking on how to ensure that displays meet sufficient display quality criteria. Although, the recommendations described here are likely to be supplemented or replaced by more clearly based recommendations in the future, these standards do offer some guidance, especially when used in conjunction with visual evaluation of display performance under realistic flight conditions.

Table 2-15. Summary of conclusions (cont. next page).

Display Parameter	Conclusion
2.5.1 Resolution (Paper, CRT, LCD)	Resolution should be as high as achievable for electronic media. For paper, an effective resolution of 300 dpi (print quality of 600 dpi) has proven to be acceptable.
2.5.2 Mean Luminance (CRT, LCD)	Manual controls, either in conjunction with or independent of automatic controls, should be made available to the user to vary mean screen luminance. The appropriate screen luminance range will be dependent upon the contrast ratio and size of displayed symbology, hence a minimum value cannot be specified. However, a range of 0.1 - 200 fL has been suggested.
2.5.3 Luminance Contrast/Contrast Ratio (paper, CRT, LCD)	<p>CRT, LCD: A minimum luminance contrast ratio of 10:1 is desirable for all viewing situations, however, a lower contrast ratio may be acceptable if adequate testing justifies a lower value.</p> <p>Paper: Instrument approach procedure charts should be printed with sufficient contrast between the characters and their background that they are easily read in all viewing situations.</p>
2.5.4 Luminance Uniformity (CRT, LCD)	For the unaided observer, non-uniformities in brightness or color should not be present. Employing photometric techniques, a large area non-uniformity of less than 20% is acceptable. For luminance variations within half a degree of arc, 50% or less is acceptable.
2.5.5 Contrast Direction/Contrast Polarity (Paper, CRT, LCD)	<p>CRT, LCD: No clear conclusion available. Either contrast direction is acceptable at this time.</p> <p>Paper: Contrast direction should be dark symbols on a light background.</p>
2.5.6 Convergence and Focus (CRT)	For the unaided observer lines, symbols and characters should have no tails, squiggles, skews, gaps or bright spots. Employing photometric measurements, misconvergence should not be greater than 0.7 milliradians.

Table 2-15. Summary of conclusions (cont. from previous page).

Display Parameter	Conclusion
2.5.7 Convergence and Focus (CRT)	To the unaided observer, symbols which should be aligned either horizontally or vertically, should appear so aligned. Employing photometric techniques, symbol alignment should be within 0.02 inches.
2.5.8 Anti-aliasing and Shades of Gray (CRT, LCD)	<p>Anti-Aliasing: Lines and characters should appear smoothly written and contain no unwanted jagged edges. Special attention should be paid to angled lines drawn on LCDs, which are the most difficult to anti-alias.</p> <p>Shades of Gray: To minimize antialiasing and chromatic distortions, a minimum of 15 gray levels is required.</p>
2.5.9 Viewing Angle (CRT, LCD)	Current aerospace recommendations require a viewing angle of 53 degrees in the left and right direction, 35 degrees above, and 0 degree below a plane perpendicular to the screen face. However, display location and additional crew member viewing may require higher specifications. Special attention should be paid to the viewing angle characteristics of any proposed LCD display.
2.6.1 Flicker and Refresh Rate (CRT, LCD)	For the unaided observer, there should be no undesired rapid temporal variation in display luminance for a symbol or display field. For CRTs, a refresh rate of 50 - 60 Hz is generally acceptable. For LCDs, a frame rate of 30 Hz may be acceptable.
2.6.2 Jitter (CRT, LCD)	For the unaided observer, a static display should contain no discernible jitter. Employing photometric techniques, image jitter should be within 0.3 milliradians peak-to-peak.
2.7 Color Discrimination (CRT, LCD)	Any use of color in electronic IAPs should be adequately tested in flight situations with a representative sample of pilots. As a guideline for the design of such devices ARP 4032 should be consulted.

3. INFORMATION PRESENTATION REQUIREMENTS FOR IAP CHARTS

3.1 OVERVIEW OF CHAPTER 3

To this point, the handbook has addressed issues concerning the visual requirements of the eye and the performance constraints these requirements place on the paper or electronic medium (Chapter 2). The remainder of the handbook builds upon this material in order to look at how IAP chart information elements should be organized and laid out to support efficient access to these elements, when required.

Chapter 3 is organized into two major sections. Section 3.2, "The IAP Chart User's Task," presents a simple framework for understanding how pilots perceptually interact with IAP charts. This description sets the stage for the remainder of Chapter 3 by specifying those unique characteristics of IAP chart use that can help to identify the subset of available experimental literature most likely to offer useful design guidance. In addition, this description provides the logical framework used to organize the presentation of this guidance information so as to best demonstrate its value and utility. Section 3.3, "The IAP Chart Designer's Tool Box," explains how the guidance information will be presented. The metaphor of a "tool box" is used to suggest that the designer has available a variety of visual "tools" that can be used to influence the perceptual system of the IAP chart user to support efficient and accurate access to desired information.

Descriptions of the individual tools, together with what is known about how they are best applied, is provided in Chapters 4, 5 and 6. Chapter 4, "Orienting Within The IAP Chart," describes a set of tools that can be used to lay out IAP chart information in a logical and consistent fashion so as to support the user's ability to quickly and accurately find that part of the chart most likely to contain the target information. Chapter 5, "Search and Legibility," describes some tools for ensuring that alphanumeric and symbolic information can be easily detected and identified. Finally, Chapter 6, "Search and Peripheral Vision," presents a set of tools that can contribute to efficient search within a given part of the IAP chart.

The tools available to the designer offer a variety of ways for improving the design of IAP charts. These tools are applied to specific parts of the chart but, together, they affect the overall appearance and usability of the chart. To ensure that the impact of each individual application of a tool as it affects the IAP chart as a whole is considered, Chapter 7 reviews the perceptual requirements that must be met by the overall appearance of the chart. Included in this chapter are some final thoughts and recommendations on how best to make use of the IAP chart designer's tool box. Finally, the guidance information principles developed in these chapters are listed in an Appendix.

3.1.1 How to Use the Information in Chapters 3 Through 7

A complete handbook on how to effectively present information on an IAP chart would consist of specific rules, such as what font size to use for a given piece of alphanumeric information and how much white space should be present between individual visual elements (alphanumeric characters, symbols, boundary lines, etc.). The state of our knowledge about how people perceive does not come close to achieving this objective. If it did, we could simply develop an expert system that would take the individual information pieces and produce a fully designed chart. There would no longer be a need for IAP chart designers nor, for that matter, would air certification specialists be charged with the responsibility of evaluating new charts as they are introduced.

This chapter does not even attempt to provide such specific guidance because it would be misleading at best. Instead, it offers guidance on how to think about the design of IAP charts, taking into account what is known about how people perceptually interact with these charts and, for that matter, other forms of visual displays. This understanding is supplemented by guidance information about font sizes, tools for highlighting information, and other topics. However, this guidance is, in almost all cases, less specific than might be desired. The user of this material must contribute his/her own judgment as to how this information should be used for a given application. This judgment becomes especially important in that the appropriateness of a specific tool depends upon the specific design issue in question. The suggestions contained in this chapter must be customized in their application to any specific design problem. This is *not* a cookbook that can be passively followed. Instead, it is a way of looking at chart design that, hopefully, can help to sensitize the designer to new design opportunities that may lead to more usable IAP charts.

3.2 THE IAP CHART USER'S TASK

IAP charts provide a range of information required to accomplish safe and expeditious landings under instrument (and occasionally visual) flight conditions. Because these charts are frequently accessed during the actual approach, they must support rapid access to critical information and accurate recognition of this information under flight conditions that can include extremes in lighting and vibration that can hinder easy reading of the chart.

Given the important role these charts play in supporting the flow of traffic through often busy airports, it is surprising that very little experimental attention has been devoted to identifying ways for improving their usability. The lack of direct data necessitates a look at other domains, such as typography and cartography, that might provide valuable guidance. Entering other domains means, however, that decisions must be made as to the relevance of the data for the IAP chart application. These decisions are best made within the context of some understanding of how pilots use these charts. Unfortunately, little attention has been paid to this issue as well. Cartographers, however, have developed a variety of models representing how users interact with maps in general. Examples of cartographic models (see Board, 1981, for a review) include:

- *Communication models* that are variations on the Shannon-Weaver model of information transfer (e.g. Kolácný, 1969; Wood, 1972b). In keeping with the Shannon-Weaver framework, these models emphasize the amount of information that is transferred

from the sender (the IAP chart designer) to the receiver (the IAP chart user). For the purposes of this chapter, the concern is not with "amounts" of information that are transferred but, rather, how to present that information so as to ensure that the user successfully perceives it.

- *Semiotic models* that attempt to apply semiotics, the theory of signs (see Eco, 1976, for an example of a generic semiotic model), to understanding how maps are read (e.g. Schlichtmann, 1985; Wood & Fels, 1986). These models address the "visual logic" by which signs used on maps (symbols, words, etc.) relate to the information they represent. Although this approach possesses obvious intuitive appeal, its strength lies outside the scope of this Handbook. The handbook is constrained to issues of a perceptual nature, that is, how to make the information that is presented easily perceived by the user. The meaningfulness of this information, although clearly an important issue, is not addressed.
- *Information processing models*, based upon traditional cognitive models that specify stages through which information passes as it is processed by the cognitive system (e.g. Dobson, 1979a; Eastman, 1985a). Unfortunately, these models are clearly dated and cartographic theory has failed to replace them with more recent models (Blades & Spencer, 1986). In addition, these models tend to focus on the role of memory in reading maps, devoting less attention to perceptual processes.

Clearly, these three modeling approaches do not address the specific goals of the Handbook, an important reason being that they focus on aspects of map use that are not appropriate given the focus on perceptual interaction with IAP charts. However, the development of a complete model of how pilots perceptually interact with IAP charts is also outside the scope of this handbook. In place of a complete model, a simple framework of assumptions has been developed to serve the critical role of providing criteria for evaluating the relevance of experimental data. An example of how the assumptions made about IAP chart use impact the identification of guidance information may help to demonstrate the critical role played by these assumptions.

An important issue for IAP chart design is how pilots look for information presented on a chart. The obvious assumption is that pilots *read* an IAP chart in the same sort of way they read text in a book or magazine. This assumption suggests that the pilot scans the chart, starting at the upper left-hand corner and works down through the chart from left to right and top to bottom. However, an alternative assumption is that IAP charts are scanned in a manner similar to maps, pictures, and other forms of visual display.

The research on picture and map scanning (Dobson, 1979b; see Rayner, 1978, and Castner & Eastman, 1985, for reviews) shows that the eye is drawn to high information density locations of a map or picture and jumps over low information density parts, at least during initial scans. Eye movement patterns are also influenced by pre-existing knowledge of the map or picture being scanned. With respect to IAP charts, this research suggests that the eye movements of a pilot are controlled by a combination of knowledge of how IAP charts are typically visually organized (top-down control due to expectations and prior experience), together with visual information provided by the chart being scanned (bottom-up control using visual "clues" to determine the most informative parts of the chart).

This dual-control view of IAP chart scanning suggests that there are two basic stages involved in seeking and finding a specific piece of information. The first stage involves finding the general location of a piece of information. IAP charts possess a fairly consistent overall structure, although this structure differs between NOS and Jeppesen charts. With a few exceptions, non-geographically based information (that is, information other than waypoints and other types of information that are tied to their real-world position) is found in the same general location across all charts provided by a given manufacturer. This consistency provides the pilot with an immediate advantage in that he/she knows a general location in which to begin the search.

For example, on the NOS charts, the missed approach instruction is typically located within the profile view section of the chart. Also, the pilot is likely to have an idea of the general appearance of this information: Missed approach instructions are usually blocks of text which are visually unlike most of the other types of information found in the profile view section. Consequently, these instructions are not likely to be confused with other types of information on the basis of their general appearance. Similarly, landing minima given for each category of aircraft are always presented in tabular form on the NOS chart. Without even having to read the table, its unique appearance helps to draw the eye to that location fairly quickly. This process of finding the general location of information is referred to here as *orienting*.

Once the general section has been found, the pilot then must *search* for the specific target information. The search process relies on more specific perceptual clues that help the pilot to know when that piece of information has been found. These perceptual clues are obviously specific to the type of information of interest. Again, though, consistency in the coding system used by the chart helps to support this process. Certain types of information are always located in the same place within a given section. An example of this is the name of the airport, which is always presented in the upper right-hand corner of the IAP chart, or the runway and type of approach, which always appears in the upper left-hand corner of the chart. Other types of information vary in accordance with actual geographical location, such as waypoints. In this case, the pilot knows to look for the name of the waypoint and usually has a general idea of where the waypoint is likely to be located. Still, the waypoint must be found and differentiated from all other waypoints in that general location. In still other cases, the pilot looks for a label, then finds the variable for that label. For example, a number of frequencies may be provided in the upper left-hand corner of the plan view. The pilot looks for the label (e.g. UNICOM), then the frequency beside it.

All of these examples suggest that a simplified way of understanding how a pilot uses an IAP chart is a two-stage process: The pilot first orients to the appropriate location and then searches within that location for the target information. Given this simple framework, the question then becomes one of how an IAP chart can be designed to support each process. The remainder of this Handbook looks at a set of design tools that may be useful as forms of visual "help" that can be provided to support the pilot in efficiently and accurately finding target information. These tools range from the use of lines and borders to selection of an appropriate font size and weight.

It should be pointed out that issues of legibility are included under the topic of search. Understanding the general nature of the search process should explain why legibility is not treated as a separate process. When we search for something, we not only must find it but must also be able to confirm that the something we have found is in fact what we are looking for. Consequently, there is an inherent requirement for information recognition in the search process. Take the case of the pilot searching for the RBV waypoint. To simplify, the pilot knows she has found RBV

when she is able to recognize RBV on the chart. If she finds some other waypoint and mistakes it for RBV, her search process has failed. Legibility issues fit in with search issues because they contribute to the search process by influencing the speed and accuracy with which the recognition part of search takes place. An illegible name on a chart slows down the search process and may also contribute to the occurrence of an error.

3.3 THE IAP CHART DESIGNER'S TOOL BOX

The previous section emphasized the roles of prior knowledge and visual elements on the IAP chart in determining pilot accuracy and efficiency in perceptually interacting with a chart. The IAP chart designer obviously cannot manipulate the chart reader's prior knowledge. However, the designer can use a variety of "tools" for attracting and influencing the movements of the eye.

These design tools are already in use on existing IAP charts. White space is used to separate individual information items while variations in font size are used to code the relative importance of some types of information. However, it may be possible to use these tools more strategically and with a well thought-out logic to enhance the visual quality of existing charts. It is the goal of the next few chapters to encourage a reevaluation of how these tools are used.

Chapters 4, 5 and 6 comprise a review of these tools, together with available data as to when they are best used (or not used). In Chapter 4, design tools that can be used to support the orienting process are described. These tools are used with the primary goal of clearly specifying the major sections of an IAP chart so as to enable the pilot user to visually access each section quickly. Tools available for this process include:

- Distinctive Visual Appearance
- Standard Location
- Boundary Boxes
- White Space as Boundaries
- Proximity
- Similarity
- Contrast

Chapter 5 describes the visual tools that can be used to ensure that alphanumeric and symbolic information can be easily discriminated from the chart background and from each other. Two sets of tools are described:

- Font Characteristics (e.g. size, weight)
- Symbol Characteristics (e.g. line weight, fill)

Chapter 6 addresses the issue of how to develop a chart that supports efficient visual search once a specific portion of the IAP chart has been accessed. A number of tools are available for this purpose and they fall into the following categories:

- Information Highlighting Tools (e.g. bolding, reverse type)
- Information Coding Tools (e.g. type size coding, color coding)
- Information Bounding Tools (e.g. boxes, white space)

Several general caveats should be made, however, before describing these tools. First, specific rules defining when a tool should or should not be used cannot be provided. Instead, each tool is described in terms of its likely effect on visual performance and the conditions under which its effectiveness (or ineffectiveness) have been experimentally demonstrated. The intent in presenting this information may best be understood by means of a metaphor. The tools presented in Chapters 4, 5 and 6 constitute a kind of "Lego set." When a child uses Lego pieces to construct a toy, each piece serves as both the material that forms the toy and the tools for attaching the pieces together (the snaps used to connect pieces are part of each piece). It remains for the child to decide which pieces to connect. Similarly, the design tools described here comprise both the material and the tools. The material consists of the lines, color, textures, and other visual elements that appear through application of a tool. The tools for attaching the pieces together are inherent in the logic of each design tool. As will be shown in Chapters 4 through 6, each design tool possesses its own logic which constrains the conditions under which that tool can be used. This logic, in a sense, serves as the "snaps" for employing a number of design tools to create an integrated and coherent chart visual structure. As is the case with Legos, the user must determine how to sensibly use them.

A second caveat stems from the impact map complexity has on the experimental process used to assess the effectiveness of map design. A map's overall appearance is a function of a large number of variables, each of which reflects the use of one or more of the tools described here. In testing the effectiveness of one or more of these tools, researchers have had to narrow the scope of their inquiry by not looking at how each tool's effectiveness is impacted by all of the variables found on a given map. Consequently, there are likely to be hidden interactions that have yet to be identified. The experimental results described here are valid for those conditions which define the experimental environment in which the data were acquired. Potential difficulties may arise when these results are applied to other situations (Bartz, 1970; Petcherik, 1983).

In addition, it should be remembered that each time these tools are used, there must be an awareness of how their use impacts the overall appearance of the chart. Inappropriate or heavy-handed use of a tool can upset critical visual dominance relations, causing visual confusion that can obstruct efficient perceptual interaction with the chart. Some criteria for how to avoid this problem are described in Chapter 7.

Finally, it is important to remember that IAP charts will be used under a variety of conditions to achieve a range of user objectives. This means that the target information in one situation may be the to-be-ignored information in another situation. Making one piece of information especially attractive to the eye means that in some cases that attractive information will draw the eye away from target information. Optimal design must balance the attractiveness of comparable information elements, since only one element is likely to be desired at any one time.

4. ORIENTING WITHIN THE IAP CHART

4.1 OVERVIEW OF CHAPTER 4

IAP charts are designed to provide various types of information that may be needed by the pilot during a flight. To be effective, these charts must support efficient and accurate access to specific information when it is required. To this end, chart information must be organized in accordance with a logic that will enable the chart user to understand the layout of the chart and anticipate where specific pieces of information are likely to be found. This *organizational logic* must then be embodied in the chart, by means of visual elements and appropriate layout of these elements, in the form of a *visual structure*.

The concept of visual structure is critical to effective chart information layout. Robinson (1952) compares the process of structuring visual information to the writing process. "One of the essentials of writing deals with the maintenance of a proper relationship among the features being presented. The appropriate amount of detail and emphasis should be applied to each element. A visual composition likewise ought to be devised and arranged, insofar as possible, so that each component appears logical both as to position and degree of emphasis. There is little fundamental difference between the construction of a written outline and a visual outline. The techniques are different, but the functional bases are the same" (p. 69). The visual structure of the chart is the primary means available to the pilot for determining the organizational logic used to position information on that chart.

An effective visual structure is based upon two elements. First, the organizational logic used to determine which information elements should be presented together must be sensible and in keeping with the needs and thinking styles of the chart user. For example, existing NOS charts (see Figure 4-1) are based upon an organization that, at the highest level, assigns chart information to one of five major categories (plan view, airport sketch, etc.). The chart user's understanding of this category structure enables him/her to anticipate the types of information to be found in each category.

Determining how the information on a chart should be organized is not a simple matter, nor is it likely that there will be general agreement as to what this organization should be. Regardless of the scheme used, it is important to remember that the success of a chart's visual structure is critically dependent upon the organizational scheme used to categorize chart information and the pilot's understanding of this scheme. A poor organizational logic necessarily results in a weak visual structure and an inadequate IAP chart.

A second critical determinant of visual structure is the way in which the organizational logic is embodied in the visual appearance of the chart. The objective is to take advantage of the strengths and "preferences" of the visual system so as to support efficient and accurate percep-

Margin Identification

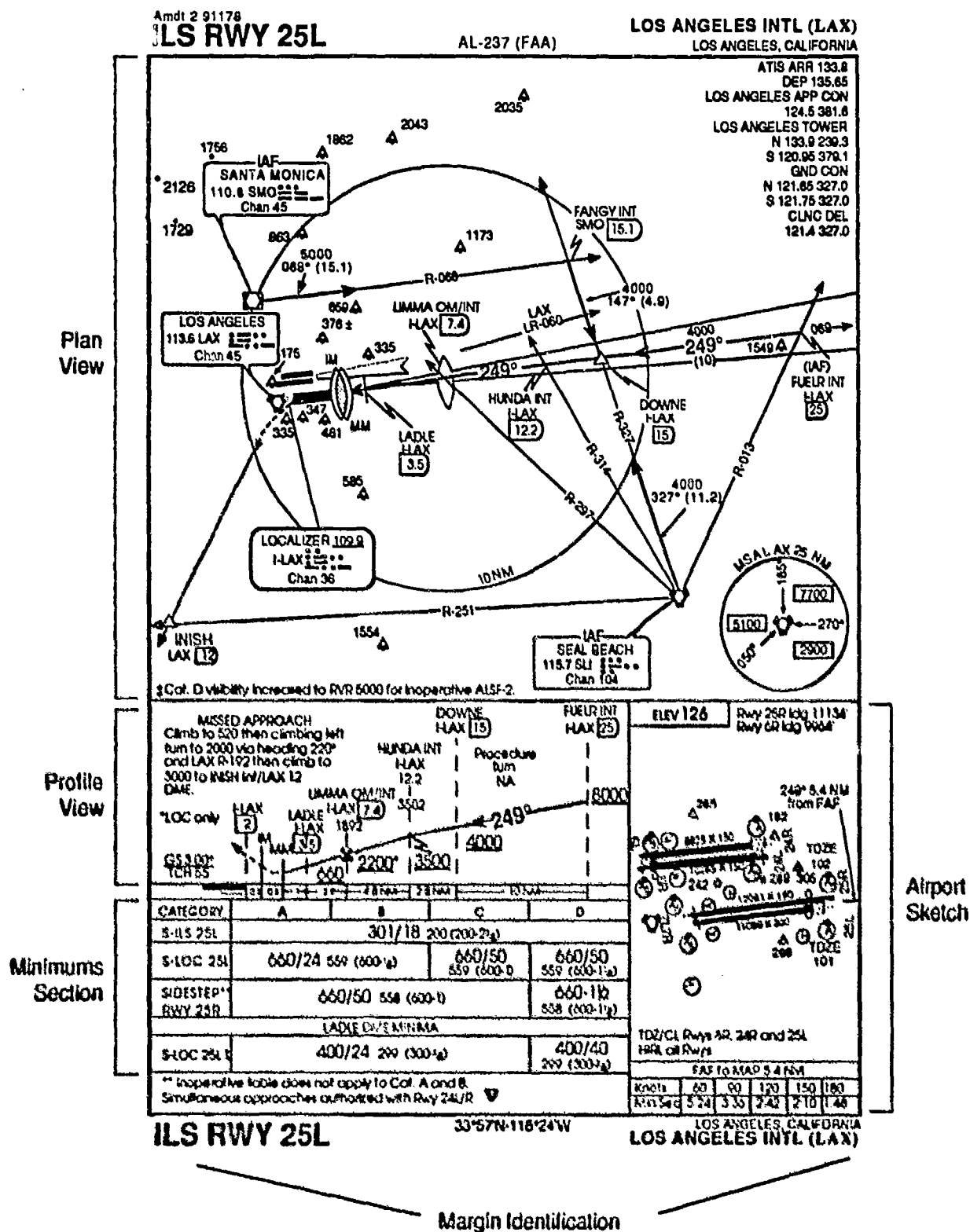


Figure 4-1. Major parts of the NOS IAP chart.

tual access to information. Our visual system responds in characteristic ways to visual information, enabling the designer to influence the movements of the eye through strategic use of visual elements that tend to attract the eye. The advantage of this approach is a substantial reduction in the cognitive demands made on the pilot. It is, of course, possible to compensate for a cluttered, disorganized chart by paying close attention to the chart, searching painstakingly through each part of the chart, and attempting to make sense of the information displayed. The cost, however, is substantial. The effort devoted to trying to work with the chart is effort taken away from the other tasks the pilot must perform. There is also the increased risk of misreading the chart. A better design approach is to take advantage of the strengths of the visual system, thus reducing the demands made on other cognitive processes.

This chapter provides an overview of design tools that can be used to translate organizational logic into an effective visual structure within the chart. Use of these tools is based upon the assumption that the organizational logic is hierarchical in nature. A visual structure based upon a hierarchy must address two aspects, (1) information elements and (2) relations between these elements. In keeping with these assumptions, this chapter is organized into three sections. Section 4.2 reviews the concept of a hierarchy and describes the implications of this form of organization on the overall visual structure of a chart. This section also looks at the conflicting requirements for embodying information elements and relations between those elements. An important objective for information element design is distinguishing one element from all other elements. Section 4.3 looks at tools for supporting information distinctiveness. In contrast, embodying information relations requires that commonalities between individual elements be detectable. Tools for relating information elements are described in Section 4.4.

Several comments should be made before describing how to develop a good visual structure. First, there are no hard and fast rules as to what design tools should be used and how they should be used to embody visual structure. Unfortunately, the perceptual phenomena described here are complex and not readily subject to experimental manipulation. To adequately embody an organizational logic, a variety of tools must be used. This means that the number of variables that must be experimentally manipulated quickly becomes large and the ability to relate design manipulations to variations in performance substantially more difficult. The potential is there for the positive effects of some manipulations to be masked by the negative effects of others. Also, the individual influence of a given design manipulation on user performance is likely to be small, although the combined effect of a number of variables may be large. In any event, manipulating individual variables is laborious in that each individual variation must be assessed both in isolation and as it interacts with all of the other variables.

On the positive side, the suggestions on how to use these design tools are based upon methods that are a part of accepted graphic design practice. Even though formal evaluation of the effectiveness of the design tools is lacking, we are very familiar with these tools through the variety of printed materials we read and scan on a daily basis. Although we may not be consciously aware of their use, our eyes have become very "educated" and sensitive to their guidance value.

Although we are a long way from being able to specify exactly how chart visual structure should be embodied, having an understanding of the goals is valuable. Much of what is addressed in this chapter is difficult to describe in words; understanding these concepts requires the reader to be able to see them as they are embodied in actual examples. Once the concept is understood, applying it may prove difficult because effective use depends upon visual judgment. There are

no rules that specify distances, sizes, and other parameters that can be accurately measured. This may be one reason why there is very little data available to prove that these concepts are important. However, the concepts possess sufficient face validity to suggest that they should not be ignored.

An additional complexity stems from the chart information itself. As was mentioned earlier, an effective visual structure depends upon having a good understanding of how the information should be logically organized. In laying out an IAP chart, decisions are made as to where each piece of information should be positioned on the page. These decisions take into account similarity between information elements, their relative importance, and other factors which should influence information location. With respect to NOS charts, it is clear that more than one organizational scheme is employed. The chart organizational logic clearly shows the influence of information importance as an organizing scheme. For example, the name of the airport, runway, and type of approach displayed in a chart is given a dominant position on the chart for the obvious reason that this information is critical to ensuring that the pilot has accessed the correct chart. Similarly, communication frequencies are prominently positioned.

The NOS logic also shows the influence of an organizational scheme that is based upon phase of flight. Margin identification is used first to select the appropriate chart and ensure that it is current. The plan view is used early in the approach since it serves to aid the pilot in orienting towards the airport and runway. The information provided in the profile view and landing minimums becomes more critical after the appropriate physical orientation has been achieved. Finally, the airport sketch can be used to aid in maneuvering on the ground.

Organization of information on the basis of phase of flight has not been consistently utilized on NOS charts. There are a number of valid reasons that preclude consistent implementation of this organizational scheme. First, the information placed in a given flight phase location may be accessed during other flight phases to support the pilot's cognitive requirements for orienting and spatial awareness. In addition, the need to ensure that critical information, such as communication frequencies, are prominently located precludes consistent use of a single organizational logic. A third cause stems from the tight space constraints of the chart which can result in there being too much information to fit into a given location. That information which does not fit must then be placed elsewhere on the chart. Finally, and most importantly, pilots differ in their information requirements. In planning their approach, variations in information needs are likely to occur.

Attempting to satisfy all of these functional requirements and constraints means that developing a useful organizational logic is a difficult but necessary process since this logic defines the information pieces and relations between these pieces that will then be embodied in the visual structure of the chart. The development of an organizational logic is not directly addressed in this Handbook but examples of such a logic are shown throughout the Handbook to demonstrate how the use of design tools are critically driven by this logic. Design tools are intended to convey meaning, and this meaning is provided by the organizational logic.

Because there is no agreed-upon organizational logic, the examples have been developed in two ways. Some examples use the existing organizational logic of the NOS chart to show how the tools are being used. Other examples are based upon what *could* be done. For example, if the organizational logic argues for treating all waypoints as conceptually belonging to the same

category, *then* tools such as using the same size or pattern could be applied to the waypoint symbols to emphasize their similarity. These examples are intended to demonstrate how the design tools can be used. They are not intended to argue that the organizational logic used in the example *should* be used. Such determinations must await further study.

4.2 THE VISUAL STRUCTURE OF AN IAP CHART

The term, "structure," is defined here as "the formal configuration of elements, parts, or constituents comprising a particular arrangement" (Cavalier, 1988, p. 301). This definition emphasizes two aspects of structure: The individual elements that together comprise the overall display and the relationships among those elements. A well-designed chart supports easy detection of the primary parts of that chart, together with visual guidance suggesting how these parts relate to each other.

The ease with which parts and part relationships are detected is influenced by the graphic format used to present that information. The term, "graphic format," is used here to refer to the form in which some subset of information is presented. A given set of information can usually be presented by means of more than one format, such as line drawings, tables, diagrams, and maps. The best format for that information depends upon what aspect of the information is considered to be of greatest interest. For example, directions to a specific location can be provided by means of a map; a paragraph description; or a table which lists, in order, the actions to be made ("turn right, heading 257") and the locations at which the action is to be performed (at RBV). Clearly, some formats are likely to be more helpful than others, although individuals may vary as to which format they find to be most useful.

For IAP charts, four types of graphic formats are typically used (see Figure 4-2):

- *Topographical layouts* (maps), which provide a simplified representation of a finite geographical space. These layouts are used in the plan view and the airport sketch.
- *Graphic layouts* (diagrams), which provide an iconic representation of a pattern of information. A graphic representation is used in the profile view to show important information about the vertical approach path.
- *Textual format* (running text), which provides descriptions of missed approaches and other verbal descriptions.
- *Tabular format* (tables), which are used to list landing minimums and approach times at specific airspeeds.

The unique qualities of each format must be kept in mind when applying the guidance information described here. Not all of the guidance information will apply to each type of format. The attempt has been made to point out applications to different formats, as appropriate.

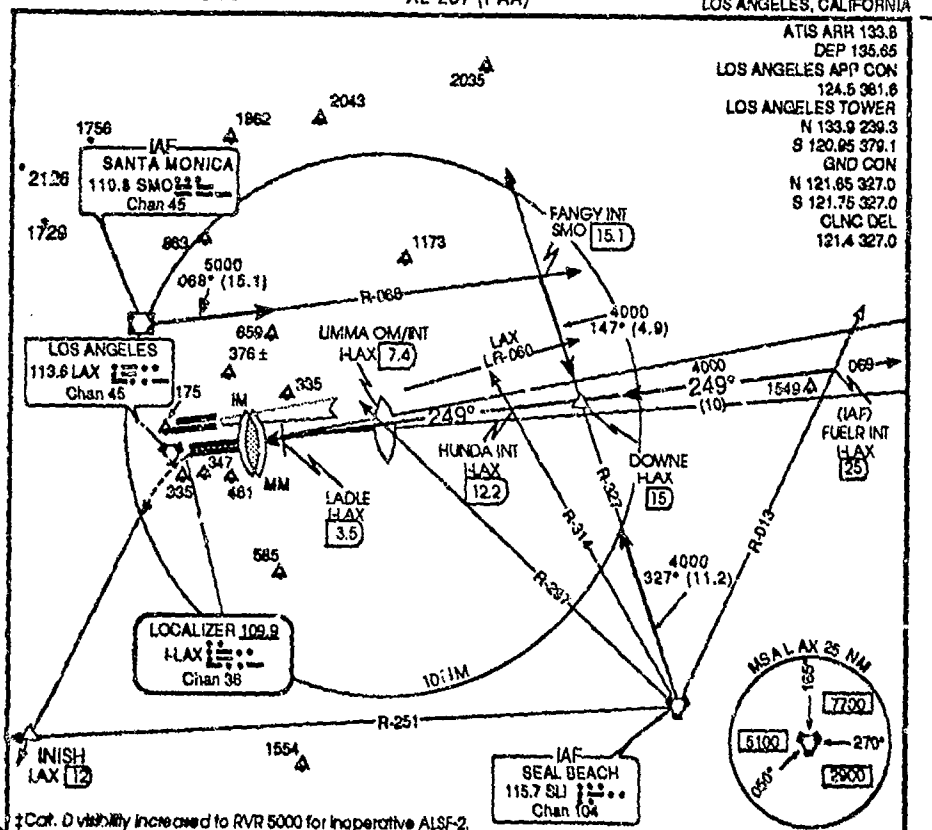
All of the formats do share a common structure, in that they are all hierarchical in nature. This means that there are levels of information, with the highest levels in the hierarchy consisting of the largest chunks or number of individual elements (see Figure 4-3). Each chunk is comprised of smaller chunks until the lowest levels, the individual elements, are reached. In the case of the

Amdt 2 91178

ILS RWY 25L

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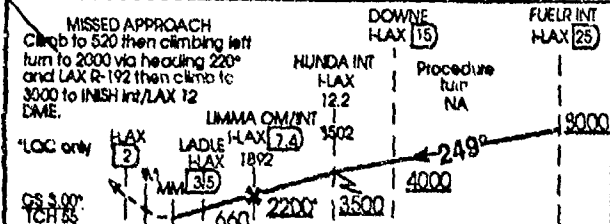
Topographical
Layout

Textual
Format

Graphic
Layout

Tabular
Format

† Cat. D visibility increased to RVR 5000 for Inoperative ALSF-2.



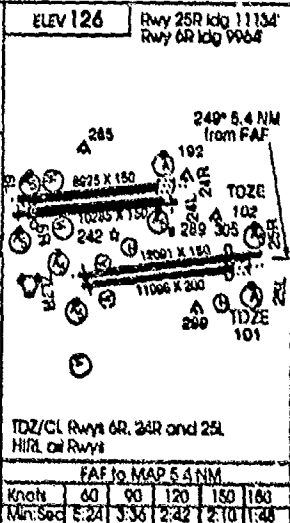
CATEGORY	A	B	C	D
S-ILS 25L	301/18 200 (200-21)			
S-LOC 25L	660/24 559 (600-1)	660/50 559 (600-1)	660/50 559 (600-1)	660/50 559 (600-1)
SIDESTEP**	660/50 558 (600-1)	660-1 558 (600-1)	660-1 558 (600-1)	660-1 558 (600-1)
RWY 25R	LADLE DME MINIMA			
S-LOC 25L	400/24 299 (300-1)	400/40 299 (300-1)	400/40 299 (300-1)	400/40 299 (300-1)

** Inoperative table does not apply to Cat. A and B. Simultaneous approaches authorized with Rwy 24L/R.

ILS RWY 25L

33°57'N-118°24'W

LOS ANGELES, CALIFORNIA
LOS ANGELES INTL (LAX)



Topographical
Layout

Tabular
Format

Figure 4-2. Types of formats used on IAP charts.

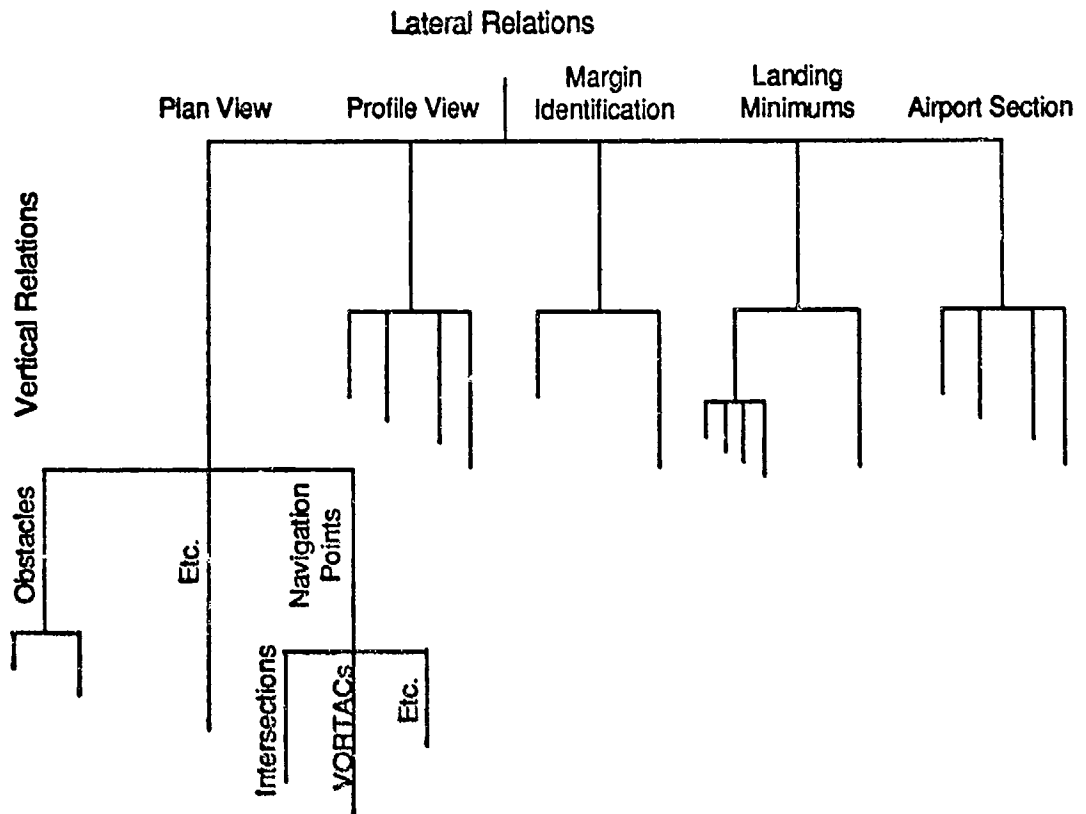


Figure 4-3. Hierarchy.

NOS charts, the highest level is defined by the five major sections of the chart. Each level comprises chunks or information elements that share some conceptual property. This shared property is a relationship. For example, the plan view contains all of the information that relates to geographical orientation, including runway location and important waypoints that can be used for determining one's own path and orientation relative to the runway. Other types of relationships that might be used include:

- *Equality of importance.* A hierarchy could be constructed on the basis of importance, for example, as related to safety, with the more important information being positioned higher up in the hierarchy.
- *Phase of flight.* Each phase of the flight involving the use of an IAP chart could have its own section of the chart. All of the information relevant to large-scale navigation involved in getting to the runway could be in one location (e.g. plan view) while the details of transitioning down to the runway (e.g. profile view) would be elsewhere.
- *Same type of information.* For example, waypoints might be differentiated from other types of navigation information in order to allow the chart user to visually move from one waypoint to another.

- *Frequency of information access.* Some information elements may be frequently accessed by the chart user while other elements are rarely used. Information elements could be hierarchically organized on the basis of access frequency

The relationships used to group information elements are determined by the organizational logic of the chart. It is likely that the hierarchy will be based upon more than one type of relationship. In the NOS charts, for example, all of these relationships can be found in various parts of the chart. Keeping them sorted out then becomes an important goal of chart design. Regardless of the type(s) of relationship used, the goal is to emphasize the sharing of a common property. Design tools can then be used to show that the individual elements "belong together" (in a conceptual sense, not necessarily a physical sense) so as to support movement of the eye from one element belonging to a group to another.

Showing group membership of chart elements is important but must not be done at the expense of inhibiting detection of individual information parts or elements. Individual elements must be clearly distinctive so as to enable rapid discrimination between them. It is likely that the chart user will ultimately be interested in one waypoint at a time. Emphasizing the shared group membership of all waypoints is important but must not reduce the user's ability to utilize the available information about the target waypoint once it has been found. Tradeoffs between discriminability and commonality will have to be made.

The remaining two sections of this chapter describe the design tools that can be used in supporting discriminability of parts and relationships between those parts. It is important that these tools be used *after* the organizational logic of the chart has been specified. This organization will determine how the information should be laid out on the chart and influence how the design tools should be used. Consequently, the first tool for design, then, is of a conceptual nature.

Before beginning the design process, prepare a hierarchical organization that specifies the categories of information that will be used and the elements that belong to each category. Define the categories on the basis of the types of relationships to be emphasized in the design.

4.3 SPECIFYING PARTS

In keeping with the hierarchical nature of the organizational logic, an IAP chart possesses multiple levels of parts, the highest level being the major sections of the chart, the lowest level being the individual information elements. This chapter provides guidance on how to design an IAP chart that enables the user to quickly identify that part of the chart most likely to contain the target information. The emphasis, therefore, is on how to visually differentiate the larger parts of the chart. Guidance on differentiating individual information elements is described in Chapter 6. It should be noted that the same basic visual processes are used to differentiate parts or elements at all levels of the organizational hierarchy. The decision to address part differentiation and element differentiation in two separate chapters is based upon the assumption that the guidance information can best be explained if it is oriented specifically towards a given informational level. The principles of part differentiation are, in many respects simpler at the higher levels. Differentiating individual elements is greatly influenced by the type of element being considered, for

example, alphanumeric characters versus symbols. Chapter 4 presents broad principles that underlie the more specific guidance provided in Chapter 6. Familiarity with these broad principles should help to make the more specific principles described in Chapter 6 easier to understand.

In considering how to differentiate the major sections of the chart, the concept of a *frame* is useful (see Figure 4-4). "Framing is the imposition of a structure that makes image areas distinct. It causes the eye to pause in its travels through space. It initiates a transition from the random texture of the environment to a specific point, or points of focus" (Cavalier, 1988, p. 305). A frame defines a part of the chart as a self-contained section comprised of individual elements that are both spatially and conceptually related to each other. Framing thus defines the limits of a particular conceptual space, specifying both the limits of where a body of conceptual information exists and serving to define visual boundaries that can help to prevent the eye from unintentionally wandering into other frames.

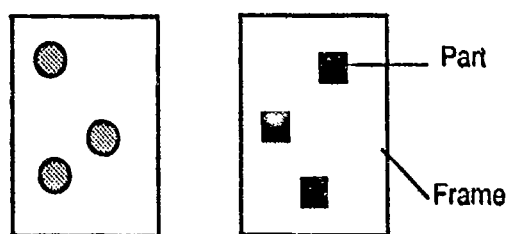


Figure 4-4. Frames.

A frame can be defined in two ways. If the chart section possesses a strong, coherent visual shape or pattern, the overall figure defined by that section will enable the section to "hang together" visually. This approach is effective if the individual parts of the section are able to, together, comprise a uniform region of connected parts (Rock & Palmer, 1990). A second approach is to clearly define the boundaries of the section by means of boxes, lines, or white space.

Ideally, both methods should be used redundantly in order to provide the strongest differentiation of individual frames. However, each chart section contains a number of information elements whose location on the chart is defined by factors outside the control of the chart designer, in particular, those elements which represent geographical locations. Consequently, the designer may have little influence over the overall figure comprised by the individual parts of a section. However, figural definition can take place in a slightly different way, that of ensuring that each chart section has its own distinctive appearance.

Given these dual methods of specifying frames, the primary design tools available for differentiating chart sections are:

- Distinctive visual appearance

- Standard location
- Boundaries

4.3.1 Distinctive Visual Appearance

Although it is not always possible to define individual chart sections by means of a strong visual form, ensuring that each major section of the chart has its own unique visual appearance does contribute towards supporting the ability of each chart section to define itself through its own form. Use of this tool is made possible by the variety of types of information that need to be included on a chart. Section 4.2 described several graphic formats that are used to present chart information. The plan view and both airport views use a topographical layout, in contrast to the tables used to present landing minimums and the diagram used for the profile view. Also, each section differs radically from each other in size, basic shape, and location on the page. These unique section appearances help the user to quickly confirm that the desired part of the chart has been reached. Consequently, it is important to preserve these distinctive appearances by, for example, avoiding the use of multiple tables for presenting very different types of information, unless these tables are visually distinctive (e.g. very different sizes). Similarly, these tools imply the need to avoid using long lists of information items or large amounts of running text.

Preserve the unique appearance of each major section of the chart.

4.3.2 Standard Location

A time-honored human factors principle for laying out information is to assign categories of information to standard locations. A standard location allows the user to develop expectations as to where categories of information can always be found. This allows the eye to automatically move to that part of the chart without having to scan the entire chart. Use of standard locations can occur at all levels within the hierarchy. For example, on the NOS charts, the profile view section of the chart is always located near the lower lefthand corner of the chart. Within this section of the chart, the missed approach instructions can be found in either of two locations, depending upon the direction of the runway approach. By using standard locations at multiple levels within the organizational hierarchy, both the orienting and search processes (described in Chapter 3) are supported, enabling more rapid access not only to a section of the chart but also to the specific, target information.

Whenever possible, design the chart to have standard locations for categories of information and, when possible, for individual information elements.

4.3.3 Methods for Defining Boundaries

Once the correct part of the chart has been reached, it is important to specify the boundaries of that section. In searching for the desired target information, the eye can accidentally move into another section, thus needlessly expanding the amount of chart space that must be searched. Boundaries avoid this problem by providing visual limits that keep the eye within the appropriate chart section. Several types of bounding tools are available. Boundary boxes are currently

used on NOS charts (see Figure 4-5). The lines of the box clearly distinguish the borders of each section. A second type of boundary is that of a line. Lines are frequently used to define the columns, rows, and cells of a table. They also can be used to separate higher-level information chunks in place of a complete box.

Boxes and lines offer distinctive ways of separating one space from another. They can, however, help to clutter the chart, especially if the section being bounded already possesses a substantial number of line elements. In this case, a more effective tool might be the use of white space as a boundary. The eye tends to ignore white space in favor of more informative elements such as lines. In effect, white space encourages the eye to "stop." Consequently, white space can offer a "cleaner" method for defining section boundaries in comparison to boxes or lines. White space can also be used to represent hierarchical differences by varying the amount of space used to separate elements at various levels in the hierarchy. To separate information chunks at the highest levels in the hierarchy, large amounts of white space should be used. Progressively smaller amounts to separate elements at lower hierarchical levels help to maintain hierarchical level distinctions.

Use a bounding tool to define parts of a chart. Boxes provide the strongest method for visually bounding a space. Lines are a more subtle method that is especially useful for defining lower-level boundaries such as between elements in a table. To avoid further cluttering a chart that already possesses a large number of line elements, white space can be used.

4.4 SPECIFYING RELATIONSHIPS

Section 4.3 described some tools that can be used to differentiate sections and individual information elements. This section looks at how relationships between items can be embodied in the chart. The design goal of relationships is to visually emphasize commonalities between individual pieces or types of information. The goal is to provide a "path" for the eye to follow from one related element to another. These paths, together, comprise a visual pattern that can be detected while at the same time preserving the distinctiveness of the individual information pieces. Patterns thus become an important means for conveying the visual structure of the display.

Cavalier (1988) describes the types of relationships that need to be visualized for a hierarchical organization: "To create hierarchy is to initiate a transition from one state, where individual elements function at the same level of value to another state, where individual elements are given greater or lesser importance. Hierarchy is a condition which structures sequential operations between diverse components. It regulates the process of transition so that it occurs between functions which are arranged and linked in order of importance" (p. 319). Implied in his description are two basic types of relationships that must be considered (see Figure 4-1). *Vertical relations* refer to relations between items across multiple hierarchical levels. In a sense, vertical relations exemplify the concept of a hierarchy: Multiple sets of information are nested within a higher level representing some property shared by the information sets. For example, the specific landing minimum values for each aircraft category vertically relate to the higher-level category,

"landing minimums." *Lateral relations* reflect a common property shared by all of the information elements within a given level. Effective chart design must support both types of relations.

The concept of a frame was introduced in Section 4-3 to refer to a group of items belonging to the same hierarchical level. This concept was introduced in the previous section in reference to the major sections of the chart. For example, the chart designer might wish to emphasize the distinctiveness of intersections as a class, perhaps by using an intersection symbol such as a triangle. VORTACs, because they belong to a different class of objects, would have a different symbol. All of the intersections are thus treated as belonging to one frame while the VORTACs belong to a different frame. Since both intersections and VORTACs are likely to be found in the same section of the chart, the chart designer might wish to *layer* the frames, allowing them to be located near each other but keeping them visually and conceptually separate (see Figure 4-6). A series of frames can be layered on top of each other to support vertical relations in that both intersections and VORTACs share membership in the higher hierarchical level of geographical information.

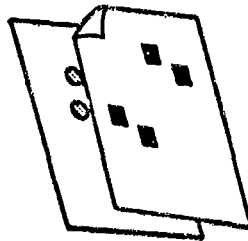


Figure 4-6. Layering.

The concept of layering derives from our experience of objects in a three-dimensional space: "Three-dimensional space has an almost infinite potential of visual planes, receding from the eye, which can contain the objects of the external world" (Wood, 1968, p. 58). There are a number of forms of visual information that enable us to differentiate near objects from those located farther away. These forms of information can be applied to distinguishing information elements which are assigned to different information layers (Dent, 1972; Wood, 1968).

Attempting to embody both lateral and vertical relations can quickly become complicated. However, each approach has its own set of design tools. The choice of these tools is determined by two factors:

- The type of hierarchical relation being embodied (lateral or vertical);
- The location of the related items, that is, whether the related elements are located close to each other or are separated on the chart.

Combining the two dimensions of type of hierarchical relation (lateral or vertical) and location (close or separate) produces a two-by-two matrix comprised of four cells:

- Items belonging to the same hierarchical level and located next to each other.

- Items belonging to the same hierarchical level and not located next to each other.
- Items belonging to different hierarchical levels but located next to each other (or, in many cases, on top of each other).
- Items belonging to different hierarchical levels and not located near each other.

Table 4-1 shows the categories of tools available for specifying each of the four types of relations. These tools are described in the remainder of this Section.

		Hierarchical Level	
		Same (Lateral)	Different (Vertical)
Location	Same (Near)	Proximity Bounding	Contrast Interposition
	Different (Separate)	Similarity "Pointing" "Leading"	Similarity

Table 4-1. Types of Hierarchical Relations

4.4.1 Same Hierarchical Level, Same Location

The hierarchical nature of chart information organization suggests that distinguishing major parts of a chart is, in some respects, the same concept as showing relationships between parts. It all depends upon what level in the hierarchy one is talking about. For example, at the highest level of the hierarchy, a part is a major section of the chart. However, those elements that are nested within the highest level (i.e. the next level down in the hierarchy) belong to that level because of some shared property. When the intention is to show membership in a category, the simplest method is to locate them in the same section of the chart.

4.4.1.1 Proximity

The principle of proximity refers to the "assumption" made by the visual system that items which are located close to each other are somehow related. "Proximity develops the expectation that what we see occurring in a particular frame forms a particular system. To create proximity is to interrupt a random pattern by grouping elements into sets. It is a transition from a state of formal independence (patterning) to an inter-dependence (bridging) between individual elements as they appear and how they operate as a group. The space between individual elements unites them in the formation of an apparent system" (Cavaller, 1988, p. 314). Proximity, for example, is a key tool for labeling symbols. That label which is closest to the symbol is assumed to belong to it. Proximity also relates the individual elements of a table.

Proximity provides a strong visual cue for shared category membership.

4.4.1.2 BOUNDING

Proximity relations are most effective if they are supported by an obvious visual frame. The frame, in effect, defines the limits on which information elements are defined as proximally related. Tables offer a good example of combining proximity with the use of bounding tools. Tabular information is presented in a series of cells created through the coming together of rows and columns. Rows and columns are created through sequences of information elements that are oriented both vertically and horizontally. When space is not a constraint, variations in spacing between elements at different levels in the hierarchy offer an effective tool for representing the hierarchical nature of the table. Table 4-1 shows how this principle works. The greatest amount of white space defines the boundaries of the table itself. Smaller amounts of white space separate the individual cells within the table while the smallest space separates the words within the same cell. If there is not enough space available to maintain an appropriate ratio of space between cells versus space between the table and non-table information, the use of lines is required. These lines can then serve as boundaries which define the spatial limits of the table. This is the approach used in NOS charts (see Figure 4-7).

CATEGORY	A	B	C	D
S-ILS 25L	301/18 200 (200-2)			
S-LOC 25L	660/24 559 (600-1)	660/50 559 (600-1)	660/50 559 (600-1)	660/50 559 (600-1)
SIDESTEP** RWY 25R	660/50 559 (600-0)			660-1 1/2 559 (600-1)
	LADLE DME MINIMA			
S-LOC 25L	400/24 299 (300-1)		400/40 299 (300-2)	

Figure 4-7. The use of bounding lines on NOS charts.

Use of the bounding tools (boxes, lines, white space) should be considered when using proximity as a tool for defining shared category membership.

Tools such as standard location and boundaries can be used to specify related information if the information elements that possess the shared property can be physically located near each other.

4.4.2 Same Hierarchical Level, Different Location

The effective use of proximity requires that member information elements be clustered together into a common space. When the distances between individual items becomes too great, the proximity relation breaks down. Items then appear to be randomly organized. This is often the case for information presented using a topographical format. The example of the intersection and VORTAC symbols exemplifies the problem. The chart designer may wish to emphasize member-

ship in the same category for items located through the topographical layout to enable the eye to quickly move from one category member to another. Since these items must be positioned in their correct geographical locations, the proximity tool cannot be used.

Three methods can be used for specifying relatedness between items that are not closely located to each other: Similarity, "pointing," and "leading."

4.4.2.1 SIMILARITY

Our visual system tends to assume that items which look the same are similar in other respects as well. Similarity allows the visual grouping of individual elements. Also, the visual system can be "set" to look only for similar items while ignoring dissimilar items. Consequently, the eye can move quickly from one related item to another.

Types of similarity to which our visual system is sensitive include:

- Color
- Texture
- Shape
- Size

Some types of similarity, however, are more effective than others. Relative effectiveness of the similarity methods are discussed in Section 6.3 of Chapter 6.

The information elements that need to be grouped are determined by the organizational logic of the chart. Once this has been determined, it is then possible to define appropriate visual patterns for each group. The aim is to have a consistent visual pattern in a grouping and the clear differentiation of patterns across groupings.

Conceptual grouping of information elements can be encouraged by assigning a common visual property (color, texture, shape, size) to members of that group.

4.4.2.2 POINTING

A second approach is to use one symbol element to "point to" another. This can be done in several ways. A common method is to use an arrow to move the eye from one element to another, for example, from a label to its symbol. In this case, the distance between the two elements is compensated for, to some extent, by the length of the arrow. A more subtle approach is used to cross larger distances between elements. An arrow can be used to point in the *general direction* of the related element. For example, on NOS charts, a dotted arrow is placed at the end of the runway to show the path to be followed in the early stage of the missed approach procedure (see Figure 4-8). The holding pattern location may be some distance away on the chart. Rather than use a line to specify the entire path, the arrow points in the general direction of where the hold-

ing pattern is located. The eye derives its initial directional guidance from the arrow, then continues to move in that direction until the waypoint specifying the holding pattern location is found.

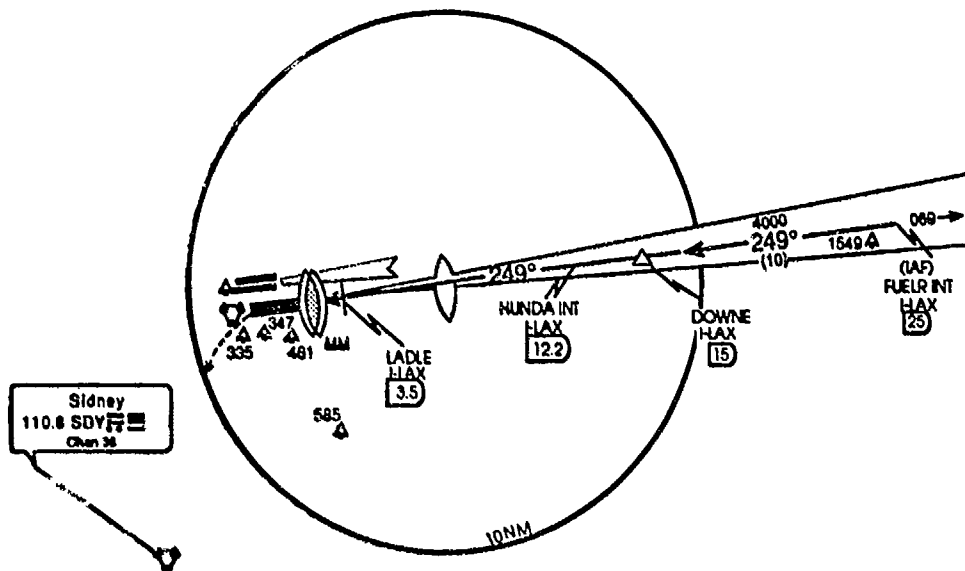


Figure 4-8. Use of pointing to specify a missed approach on an NOS chart.

As this example suggests, the eye is responsive to pointing elements. Once the movement is initiated, the eye tends to continue in that direction until some other element stops it. This characteristic of the visual system is both an advantage and a disadvantage. The chart designer, therefore, must consider two factors:

- Which information elements are shaped so as to cause eye movement to begin.
- What information element(s) is available to stop the movement.

The chart designer should review each information element on the chart to determine if it has the potential to cause directional eye movements. This is especially important if the element is not intended to cause such movements. If unintended directional movement by a symbol can be initiated, consideration should be given to providing a means for stopping the movement. Otherwise, the eye is likely to wander off and effort will have to be made by the chart user to return the eye to more appropriate paths.

For those elements which are intended to cause this movement, the expected path of the eye should be reviewed to determine if the item intended to stop it (e.g. the holding pattern) is placed appropriately along this path.

The method of "pointing" offers a useful tool for guiding the eye from one related item to another while avoiding the clutter that can occur from the use of lines and other direct connecting methods. If pointing is used, make sure that the path specified by the originating element will move the eye to the intended target element. Also, make sure that unintended pointing is avoided.

4.4.2.3 "LEADING"

The least subtle method for grouping widely spread information elements is to actually connect the elements to each other by means of lines. In effect, the line "leads" the eye from one point to another. The most obvious use of this method is found on the plan view to describe the approach path to the runway. While following this path, the eye will also find other, related information elements, such as the symbols for outer and middle markers.

The advantage of this approach is that it clearly defines a critical path that the eye can follow. Because the eye is drawn along this path, it will necessarily find those information elements that should be seen. This method should be used sparingly, however, because it can contribute to chart clutter. Consequently, for situations involving less critical information, other methods such as similarity and pointing should be used.

"Leading" the eye from one information element to another by means of lines or arrows provides the strongest means for relating similar elements. It should be used sparingly, however, to avoid clutter.

4.4.3 Different Levels, Same Location

In some cases, it is necessary to deal with items that belong to different information categories but must be located near or even on top of each other. This situation often arises because of space constraints. For example, in attempting to show a marker beacon which is located along a body of water, the size of the symbol may result in part of the symbol having to be positioned on top of the symbol signifying the body of water. A geographical location that is covered by the marker beacon may also need to be specified, resulting in there being a label or line symbol being placed on top of the marker beacon. The end result can be three or more symbols which all need to be positioned in the same location on the chart.

This type of situation emphasizes the value of the layering concept. Each category of symbol can be treated as belonging to its own chart layer. For example, the first layer is that of the ground. It is, in effect, the white page before any other marks are applied to it. The next layer might be terrain marks, such as those specifying bodies of water. Upon this layer might be placed location symbols, such as LOMs or marker beacons. Label information might then comprise the top-most layer. The effective use of layering depends, of course, on there being a meaningful organizational logic that is used to assign elements to specific layers. Once the organizational logic of the layers has been developed, two types of design tools can be used to support perception of multiple layers, relative contrast and interposition.

4.4.3.1 CONTRAST

The concept of layering was derived from our experience with objects in three-dimensional space. This has led to the application of three-dimensional depth cues in support of layer differentiation on the two-dimensional surface of a page or screen. All of the techniques, described under the heading of "Contrast," are based upon the perceptual phenomenon of *aerial perspective* (Dent, 1972). Aerial perspective refers to variations in distinctiveness and color of objects as a function of their distance from the observer. For example, when viewing mountains at varying distances, the farther mountains appear to be faded and less distinct, in contrast to the brighter colors and crisper shapes of nearer objects. These differences are due to light refraction through the atmosphere and also occur in achromatic situations. Distant objects viewed on a foggy night appear grayer with softer edges in contrast to closer objects (Dent, 1972).

Variations in relative contrast can be used to specify relative layer "distance" in several ways (Dent, 1972). One approach is to manipulate the contrast between the edges of information elements located on different layers (see Figure 4-9). Objects at progressively higher levels (moving from the "ground" layer up) should have progressively sharper edges. The sharper the edge, the more likely it will be that the element defined by that edge will stand out against elements with softer edges.

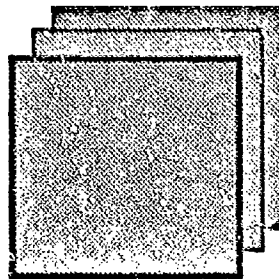


Figure 4-9. Specifying multiple layers through variations in edge contrast.

Use variations in the sharpness of edges to define multiple information element layers.

A second approach is to vary *brightness contrast*. For monochromatic patterns, the brightness of an element is determined by the ink-to-paper ratio. The higher the ink-to-paper ratio, the brighter the element appears. The objective is to have the brightest element appear to be closest to the reader; therefore, elements located on higher layers should have a higher ink-to-paper ratio than elements positioned on lower surfaces (see Figure 4-10).

This variation allows the chart user to immediately see that multiple elements from different layers are positioned on top of or close to each other. An example of this approach is used on the Airport Diagram section of NOS charts (see Figure 4-11). The runways are in black while buildings and taxiways are in gray. Both types of information are available to the chart user but the

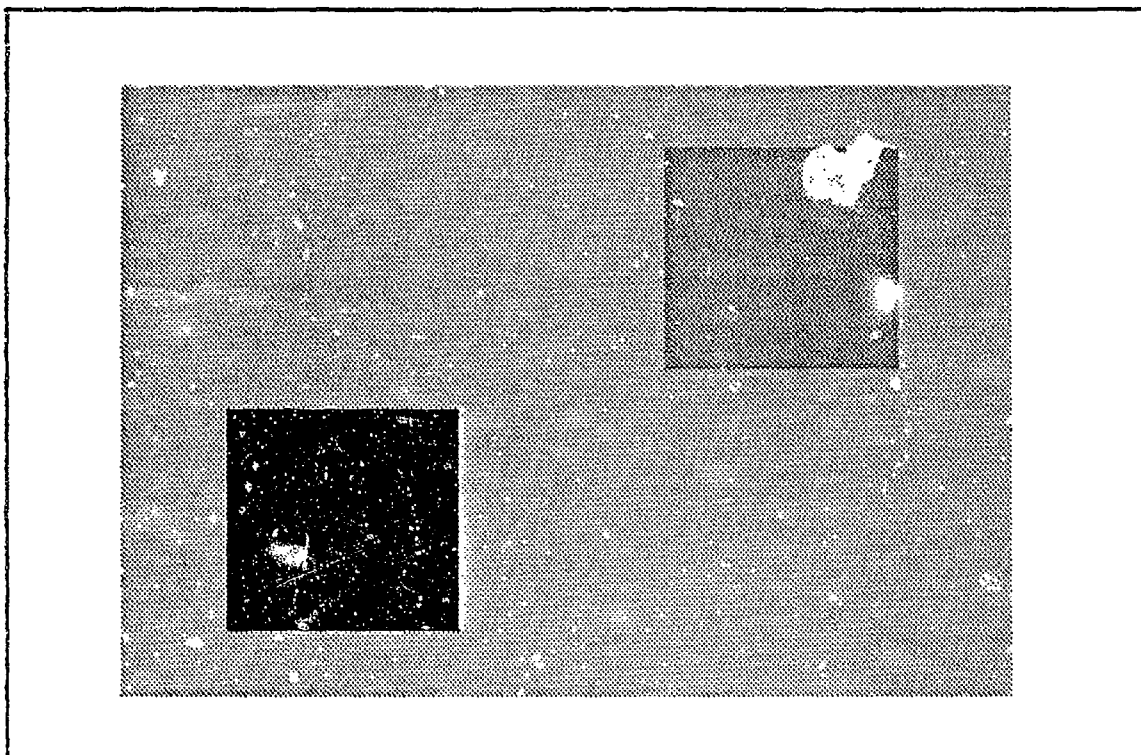


Figure 4-10. Specifying multiple layers through variations in brightness contrast.
(Adapted from Dent, 1972)

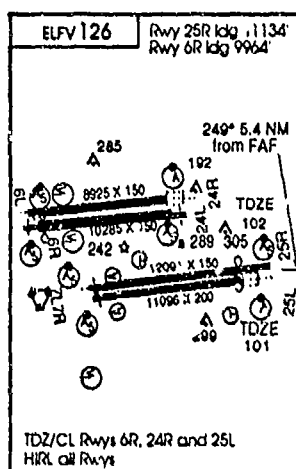


Figure 4-11. Brightness contrast used for layering on the Airport Section of an NOS chart.

runway shapes, assumed to be more important, act as the highest layer and visually dominate the section. Based upon experimental research, Dent recommends that the texture and brightness differences must be 5.0 lines per inch and ten percent respectively when the dot sizes are similar.

In terms of color, a study by Johns and Sumner (1948, cited by Wood, 1968) showed that bright colors (white and yellow) were seen as nearer than neutral gray while darker colors (green, blue and black) appeared farther away than neutral gray. These results led Wood to conclude that the richest colors should be used on the highest layers, reserving paler colors for lower levels.

Variation in brightness contrast is a useful tool for differentiating between items from different layers. For **monochromatic** charts, information elements on the higher levels should be darker than elements on the lower layers. If **color** is used, brighter colors should be used for the higher layers.

The chart designer can also vary coarseness of texture while keeping brightness constant (Dent, 1972). Dent's subjects were more likely to perceive the coarser-textured, larger-dot pattern as figure rather than finer-textured, smaller-dot patterns. This is not surprising because a finer texture also tends to have a less distinct edge. Based upon experimental evaluation, Dent recommends that a texture difference of at least 10.0 lines per inch be used to ensure maximum discriminability.

If multiple patterns that are equally bright but vary in coarseness of texture and size of dot are superimposed on each other, the coarser texture should be positioned on the highest layer.

A final contrast manipulation that can be used is *articulation* (Dent, 1985; Wood, 1968). Articulation refers to the amount of detail used on a symbol. More detailed elements tend to stand out as figure in contrast to less detailed elements, which is consistent with our experience that the farther objects are away from us, the less able we are to see detailed features of those objects. This design tool is constrained, however, by requirements for ensuring that the user can clearly see what the symbol is and distinguish it from all other symbols.

The amount of detail provided on a symbol can be used to vary contrast. Detailed symbols tend to stand out as figure against less detailed symbols.

Line elements can also be manipulated using the principles of contrast to convey relative significance. Variations in edge contrast are one example of using line contrast to differentiate element layers. Lines which comprise their own figures, such as arrows and radius lines, can also vary in line weight (see Figure 4-12).

Dent (1972) argues against differentiating visual layers by varying line weight. His concern is that edge sharpness cannot be easily controlled, thus possibly reducing line contrast to levels insufficient for adequate legibility. In addition, increasing the line weight can also result in an undesirable increase in the brightness of the line when used on electronic displays. However, if

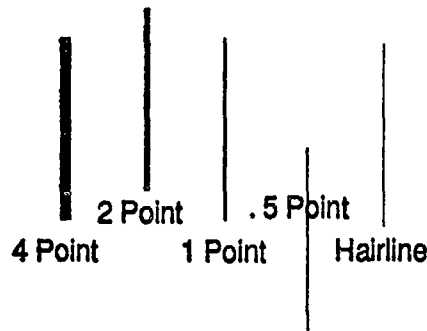


Figure 4-12. Variations in line weight.

carefully used, line weight does offer a viable approach if all variations are well above minimum contrast levels.

Varying line weight is an effective tool for signifying variations in layers if care is taken to ensure that the lightest weight provides sufficient visual contrast to be legible.

In place of manipulating line weight, Dent argues for the use of variations in line "character." Examples of such variations are shown in Figure 4-13. Several line variations are used on existing NOS charts. For example, a solid circle is used to specify the outer limits of that part of the plan view that is set to scale. Dashed circles, in contrast, denote facilities that would not appear on the chart if they were charted to scale. Another unique line character, the dashed line, is used to specify missed approach procedures on the plan and profile views.

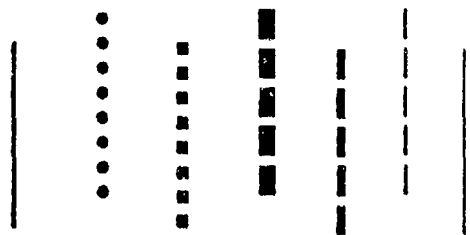


Figure 4-13. Variations in line character.

Although variations in line character offer a lot of flexibility in distinguishing types of information, the designer must ensure that each line variation used possesses sufficient contrast to be legible and is readily distinguishable from all other line variations.

Variations in line character can be useful for differentiating element layers using lines used to construct their own figures.

The variety of methods available for manipulating contrast offer the opportunity to clearly specify individual chart layers. In his study of subject preferences for certain map designs, Saunders (1961-62) concluded that "the three most favoured maps all created the impression of different visual planes, which clearly indicated the appeal of the effect and its significance for cartographic procedure" (cited by Wood, 1968, p. 59). That layering is a useful tool appears to be beyond dispute. However, for purposes of visual simplicity and ease of use, the number of layers that are used should be kept to an absolute minimum. A large number of layers means that the number of variations in texture, line weight, line character, and other aspects will quickly grow large, and will likely tax the cognitive abilities of the user in attempting to keep straight the various meanings of each element. In addition, superimposing multiple layers increases the difficulty of ensuring that all information elements are clearly legible. For these reasons, the following rule should be respec:

Use discretion in the number of layers, texture patterns, line weights, and line characters that are used. Too many may be worse than too few.

4.4.3.2 INTERPOSITION

A familiar cue for determining which of two objects is closest to us is provided when one object hides part of another object (see Figure 4-8). It is possible to specify that one information element is at a higher level than another by simply having the top object mask part of the lower object. "The contour which continues past the point of intersection in the expected direction will be seen as belonging to the covering object" (Ittelson, cited by Dent, 1972, pp. 84-85). This method is commonly used, for example, when labels are placed over lines such as the holding pattern and runway approach.

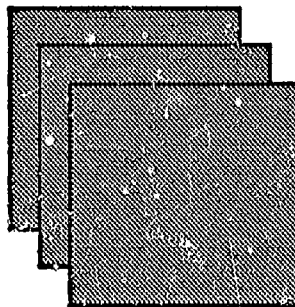


Figure 4-14. Varying multiple layers through interposition.

This method must be carefully used to ensure that the user can still easily identify the partially-covered element. The visual system tends to predict the hidden part of the shape on the basis of parts that can be seen. A line is assumed to continue as a line "underneath" a label. The elements hidden behind the visible square in Figure 4-14 are assumed to be squares because squares are familiar shapes and the visible parts of the elements suggests a square. If an unfamiliar or complex shape is used, care should be taken to ensure that the chart user is not seriously misled as to the shape of the parts hidden by a higher-level element.

Interposition provides a strong cue that one element is located in a layer that is different from another element. Care should be taken in using this tool to ensure that the partially hidden element is still recognizable and the shape of its hidden parts predictable.

4.4.4 Different Levels, Different Locations

The need for a chart designer to relate information elements that do not share a common hierarchical level or location may not be immediately obvious. Its value arises, however, when the concept of "not related" is reconsidered. A hidden assumption in all of the chart examples used to this point is that relatedness is based on a conceptual property other than simply importance. Common relations used in these examples have been geographic location relatedness, phase of flight relatedness, and so on. Relatedness due to importance has not been considered.

Many cartographers, however, argue for the need to take into account relative importance of information elements in designing a chart: "Assign visual importance and distinction commensurate with the intellectual significance of the ideas being presented. Such components as the legend box, title, and graphic scale, are not always of equal importance to the particular map or among similar types of maps" (Robinson, 1952, pp. 65-66). In the case of IAP charts, "intellectual significance" translates into operational or safety-related importance, which emphasizes the relevance of Robinson's argument for the need to introduce a pattern into the chart where variations in text, symbols, and lines occur on the basis of their relative importance.

In effect, the principle of similarity, or more correctly, dissimilarity in size is used. Larger items are more likely to be seen before smaller items. Consequently, relative importance can be conveyed through relative size. Also, using information elements that all share the same size increases the risk of introducing "confusion and monotony" into the chart (Robinson, 1952, p. 66).

As Robinson points out, however, there are serious limits as to the extent to which this principle can and should be applied. An information element may be the most important one but that does not mean it should be the largest. In choosing a size, tradeoffs must be made because of space considerations. An important element that need not take up much space can take away from other elements that inherently require a lot of space to be legible. Also, relative importance is likely to vary as a function of the user's immediate need. Although electronic media offer the potential for allowing changes in element size to occur in response to user input or phase of flight, this capability may not be available for first-generation electronic charts and certainly is not possible for the paper medium.

Variations in relative size can be made to ensure that important elements are more likely to be seen. This should not be done at the expense of decreasing the legibility of less important items.

4.5 SUMMARY

The discussion of tools that can be used to visually structure the overall layout of the chart has been presented in an attempt to respond to the need on the part of the pilot to make sense out of what he/she sees. Whenever we look at something, we unconsciously try to determine its structure: What are the major parts and how are the parts related to each other, what is important to look at, and what meaning does it have for us. The IAP chart user will find some type of structure in the chart. Ideally, this structure will correspond to the organizational logic intended by the chart designer. The information presented in this chapter is intended to help bridge the potential gap in understanding between chart designer and chart user.

Awareness of how the application of a design tool is likely to be seen by the user is an important first step towards this goal. The ideal, of course, is to be able to specifically define how each tool should be used: What textures are appropriate, what types of lines are best used to represent a given information element, and so on. We cannot, however, begin to even approach this ideal. Nonetheless, thoughtful design can, to a large extent, compensate for our lack of specific knowledge about how chart design should be accomplished. The ability to predict how each tool is likely to affect the user can help the designer judge whether and how a tool should be used, and what unintended side-effects can cause problems.

This chapter has focused on the chart as a whole. Little has been said about the individual information elements themselves and how they should be visually embodied to support the user's ability to find a desired element. This topic is the subject of the next chapter.

5. SEARCH AND LEGIBILITY

5.1 OVERVIEW OF CHAPTER 5

Narrowing the search domain to a specific part of the chart, through the guidance provided by a coherent visual structure, aids the search process by reducing the amount of map space that must be scanned. Tools for supporting this orienting process were described in the previous chapter. Once the eye has moved to the desired section of the chart, search effectiveness is determined by a combination of the pilot's familiarity with IAP charts and the visual characteristics of the information elements located there. Chapters 5 and 6 describe some of the design tools that can be used to manipulate the visual characteristics of information elements so as to help the chart user find the desired information.

Chapter 5 begins by briefly reviewing how the eye is controlled during the search process. The mutual roles of two aspects of vision, foveal vision and peripheral vision, in guiding eye movements during the search process are described. The remainder of this chapter addresses how IAP charts can be designed to support search by capitalizing on the characteristics of foveal vision. The fundamental means for improving foveal vision is by making the target information more distinctive. In the sense being used here, distinctiveness is a kind of legibility, where legibility means that each information element can be readily distinguished from all other elements. Design tools for improving information element legibility fall into two categories:

- *Font Characteristic Tools*, which support more efficient search and recognition of alphanumeric information. Examples of such tools are type size, type weight, leading, and character spacing.
- *Symbol Characteristic Tools*, which comprise methods for improving the recognition and discriminability of symbols. These tools include global symbol shape and symbol figure/ground.

Information search is also aided by peripheral vision. Aiding peripheral vision involves using techniques that serve either or both of two objectives: (1) Reducing the number of eye fixations that must be made by enabling discrimination between target and non-target information using peripheral vision; (2) Reducing visual interference from neighboring information elements that might otherwise attract the eye and slow the search process. Design tools for supporting peripheral vision are described in Chapter 7.

5.2 CONTROL OF EYE MOVEMENTS DURING SEARCH

The human eye is able to perceive detailed information only when the fovea is directed towards (fixated on) that information. This fact suggests that the eye works as a kind of spotlight, fixating the fovea on one spot and then moving, by means of a very rapid eye movement called a saccade, to another spot when sufficient processing has taken place. When reading a line of text, for example, the eye fixates several times, with each saccade covering approximately five characters at a time (Morrison & Rayner, 1981), the number of characters depending upon the cognitive complexity of the information. Section 3.2, however, pointed out that when scanning a visual display such as a map, the eye tends to move from one high information density location to another rather than following a fixed scan path. The obvious question, then, is how can the eye "know" where these locations are if it does not fixate on each part of the display?

Research on eye movements has shown that peripheral vision, which is sensitive only to gross visual detail, provides this capability. Castner and Eastman (1985) suggest that peripheral vision is sensitive to certain types of information and can recognize these information types without having to rely on foveal vision. If peripheral vision alone is not able to recognize the information, the eye will move so as to allow foveal vision to take over and bring to bear those cognitive resources required to recognize the information. The combination of foveal and peripheral vision enables the eye to skip over less informative information, enabling more efficient search.

These results led Castner and Eastman to suggest that the "attractiveness" of a piece of information to the eye may be related to the ability of peripheral vision to identify that information. Information becomes attractive when peripheral vision isn't sufficient to identify it.

This conclusion, however, is not the end of the story. Castner and Eastman go on to suggest that this stimulus-based control can be overridden by the cognitive system when the map reader is instructed to perform a specific task. Task-oriented performance tends to result in the eye moving towards those parts of the map containing information that is relevant to the task, even if this means ignoring information possessing high visual attractiveness. Under task-oriented instructions, "prominent lines, unusual or novel elements, element complexity, the presence of ancillary information, or the size and position of individual elements exerted less influence on the attention allocation of the eyes" (p. 111). Dobson (1977) emphasizes the importance of the task as a driver for how the eye moves through a map. Random map reading, without specific task instructions, results in very different patterns of eye movements than eye movements performed under task-oriented instructions.

This latter finding does not diminish the role of peripheral vision in controlling eye movements, however. Instead, peripheral vision is used, to the extent possible, to discriminate those areas with high relevance to the task from those of less relevance.

Given this general understanding of how eye movements are controlled, the obvious question is how it can be applied to LAP chart design. The research on eye movements suggests that search efficiency is improved most by reducing the number and duration of fixations required to locate target information (Bartz, 1970a; Phillips, Noyes & Audley, 1978; Steinke, 1980). At a simplistic level, this means:

- Supporting the fovea in detecting detailed information (e.g. individual symbols, alphanumeric characters, words), for example, by means of good visual contrast;

- Supporting peripheral vision by enabling this system to move the fovea more efficiently to those areas on the chart most likely to contain the target information.

Tools that may be useful in improving foveal vision performance will now be described.

5.3 FONT CHARACTERISTIC TOOLS

A large proportion of the information on an IAP chart is embodied through alphanumeric characters. Consequently, an important goal of the design process should be to develop a chart that supports efficient search for this type of information. Interest in improving the legibility of printed material dates back almost to the discovery of mechanical type (Spencer, 1969). Not surprisingly, there is a substantial body of research and accepted practice that addresses legibility issues. Much of this research has specifically concerned the question of how best to design printed materials comprised primarily of running text, such as books and magazines.

The term, "legibility," has been defined in a number of ways, and its specific meaning in a given context is often determined by the type of printed material under consideration (e.g. legibility of individual letters on license plates versus legibility of individual words in running text) and the empirical methods used for assessing it (Bartz, 1970a). This relationship between definition, type of material to which the concept is intended to apply, and the manner in which it is measured is obvious in Tinker's (1963) definition of legibility, which is generally characteristic of such definitions:

Legibility, then, is concerned with perceiving letters and words, and with the *reading of continuous textual material*. The shapes of letters must be discriminated, the characteristic word forms perceived, and *continuous text* read accurately, rapidly, easily, and with understanding. In the final analysis, one wants to know what typographical factors foster *ease and speed of reading*. Optimal legibility of print, therefore, is achieved by a typographical arrangement in which shape of letters and other symbols, characteristic word forms, and all other typographical factors such as type size, line width, leading, etc., are coordinated to produce comfortable vision and *easy and rapid reading* with comprehension. In other words, legibility deals with the coordination of those typographical factors inherent in letters and other symbols, words, and connected textual material which affect *ease and speed of reading* (pp. 7-8; italics added).

As this definition clearly shows, the phenomenon referred to by the concept of legibility is framed on one hand by the type of printed material to which it is applied (running text) and on the other hand by how it is measured (speed of reading).

To date, very little research has directly investigated issues of legibility in maps, and even fewer studies have used IAP charts as their focus. Consequently, research results in other domains supply, in many cases, the only experimental data available. These results must be interpreted with great care in that charts are visually unique from other forms of printed matter, and require the user to interact with them in very different ways that can seriously impact the relevance of data from non-map domains (Bartz, 1969, 1970a; Taylor & Hopkin, 1975). [See Bartz, 1970a, for a

thorough look at constraints that limit the applicability of the typographic legibility literature to the map domain.]

Many of the studies in non-map domains used experimental tasks and measuring techniques (see Table 5-1) that possess questionable or unknown validity to the map search task (see Tinker, 1963, for additional information about these tasks). Because so little is known about the perceptual processes underlying IAP chart use, evaluation of the applicability of these methods can be based only upon face validity. Consequently, the risk is there that application of these findings to the map search situation may be inappropriate. Speed of reading, a particularly common legibility measure, does not possess much face validity in map reading because reading a map involves finding the information before it can be read, a process that is clearly less important in reading running text. Data based upon eye movement measures, also accepted as an especially useful legibility measure, is problematic, not because of the measures themselves, but because the eye movements involved in scanning a line of text are clearly different from those used in search tasks. That there are frequently conflicting results depending upon the experimental method used (Tinker, 1963) is an important reminder that each measure may reflect a different aspect of legibility that may or may not be important for a specific type of printed matter, such as IAP charts.

With respect to the human factors literature, once again a number of legibility principles have been identified but these principles are specific to the unique requirements of the application for which they were developed, such as signage, forms, or tables. Once again, differences in the nature of the verbal material used (e.g. individual, isolated words or pieces of text which are positioned in predictable locations) and the task (reading material at a distance or scanning a form with a predictable structure) constrain the applicability of these results to the map reading task. Taylor and Hopkin (1975) suggest that the inherent complexity of maps (specifically, large-scale topographical maps) may mean that standard human factors principles are not valid for them.

Keeping these concerns in mind, tools that may prove useful for improving alphanumeric legibility are now presented. These tools are likely to contribute to more efficient search performance by increasing the distinctiveness of the words conveyed. This distinctiveness has value in two ways: First, it can support peripheral vision by allowing the alphanumeric information to stand out from potentially cluttered backgrounds; second, it may reduce the fixation time required for foveal vision to recognize what the alphanumeric information is.

5.3.1 Typeface

An obvious characteristic of type that might influence detection of alphanumeric information is the typeface used. The issue of whether typeface style influences performance has been argued for many years and a substantial proportion of typographic legibility studies, using the paper medium, have investigated this issue. The results of these studies vary, depending upon the performance measure and printed matter used.

Tinker has performed a number of studies investigating typeface differences using the speed-of-reading method (e.g. Paterson & Tinker, 1932) and eye movement measures (e.g. Tinker & Paterson, 1941). In general, his studies show that comparisons between typefaces fail to produce

Method	Description	Map Reading Validity
Speed-of-Reading	Within a given time limit, determine the amount of text read or measure the time required to read a fixed amount of text	Limited validity because IAP charts do not contain substantial amounts of running text
Visibility	Measure the threshold visibility of printed material	Results are usually comparable to acuity data (Tinker, 1963). Unclear as to how well this data applies to reading charts
Distance	Measure the distance from the eyes at which printed symbols can be accurately recognized	Similar to the visibility method (Tinker, 1963). Potentially useful for IAP chart applications
Short-Exposure	Measure quickness and accuracy of perceiving alphanumeric characters presented very briefly (1/10 second)	Questionable validity since this method allows only one fixation, a constraint that is not reasonable under real-world conditions
Focal Variator	Measure the amount of blur that still allows correct recognition	Unknown
Eye Movements	Measure the sequence and duration of eye fixations and saccades	Method is sound but results are heavily influenced by the type of reading matter used
Peripheral Vision	Measure greatest distance from fixation point at which information can still be accurately recognized	May be useful in assessing legibility of low information density parts of the chart in support of efficient search
Search	Measure time required to find names on a map	Possesses obvious relevance to the IAP chart task

Table 5-1. Common methods for assessing legibility.

statistically significant performance effects, except when unfamiliar typefaces (such as Cloister Black, an Old English typeface) are used.

Differences between typefaces have been found using measures that seem to reflect the perceptibility of individual letters. For example, Webster and Tinker (1935) showed that typefaces such as American Typewriter, Cheltenham, and Antique were superior to others, including Kabel Lite and Bodoni, when the distance method was used. Tinker (1944) compared the results obtained with several measures and concluded that visibility and perceptibility measures failed to show much agreement with speed-of-reading scores. Consequently, the impact of typeface depends upon how legibility is assessed.

Of particular interest in these studies are comparisons between serif and sans serif typefaces. Arguments for and against serifs have been grounded on a number of issues (Robinson, Abbot, & Evans, 1971). The advantage of serif typefaces, it is argued, is that the serifs support the horizontal movement of the eyes along a line of text. In addition, serifs are believed to contribute to a more distinctive shape, thus presumably supporting easier recognition of the character or word.

This argument has been countered by the view that serif typefaces typically possess variations in line weight. The serif typeface, Bodoni, shown in Figure 5-1, is a dramatic example of how severe the variations in stroke width can be. Horizontal strokes are hairline thin while vertical strokes have a much heavier weight. In contrast, the sans serif typeface, Helvetica, uses a more consistent stroke width. The variations in stroke width found in most serif typefaces raise the possibility that those parts of the character with a light line weight might "disappear" under low lighting conditions or on poorly printed pages. Sans serif typefaces, in contrast, are more likely to use a common line weight for all parts of the character, although there are notable exceptions (e.g. Optima). In spite of the arguments both for and against the use of serifs, most studies have failed to show that sans serif typefaces are read more slowly than serif typefaces. Studies that have found differences have typically used a visibility performance measure which has questionable application to the IAP chart situation. In addition, most of these studies were performed some 40 years ago when sans serif typefaces were not commonly used. Consequently, lack of familiarity with sans serif typefaces could explain any performance differences (West, 1990).



Helvetica

Bodoni

Figure 5-1. Variations in stroke width.

Based upon these results, a number of legibility experts (e.g. Tinker, 1963; Pyke, 1926; Paterson & Tinker, 1940; Spencer, 1969) have concluded that "typefaces in common use are equally legible under conditions of ordinary reading" (Paterson & Tinker, 1940). Unfortunately, it is difficult to say which line of experimental results should be followed, the visibility/perceptibility or the speed-of-reading data. Fortunately, there is some research on typefaces that used search for map names as the task. A study by Phillips, Noyes, and Audley (1977) found no significant difference in search times for names set in Times (a serif typeface) versus names set in Univers (a sans serif typeface).

Studies addressing the issue of typeface, using the electronic medium, have focused on developing a typeface specifically for electronic displays that supports maximum legibility. These typefaces were developed as a means of compensating for the low resolution of electronic systems available at the time the studies were performed. Electronic displays likely to be used for presenting IAP charts can be expected to possess sufficient resolution to support a range of typefaces beyond the very simple ones originally intended for low-resolution systems. Consequently, it would appear that the safest course for both paper and electronic media is as follows.

Use a familiar typeface that is clean and simple, avoiding unnecessary flourishes. Use of sans serif typefaces may be more appropriate than serif typefaces due to potentially poor lighting conditions in the cockpit and to avoid problems in printing or displaying typefaces with hairline stroke widths.

Although there is little evidence to suggest that typeface has a significant impact on performance, it is quite possible that the studies performed simply were insensitive to individual factors of typeface design that, together, might contribute to more legible IAP charts. These factors, which are addressed under the topics of "Type Proportions" and "Individual Character Confusions," have not been directly manipulated in the studies reviewed here. Consequently, although their value remains unproven, it is probably useful to consider their potential impact when choosing a typeface for use on IAP charts.

5.3.2 Font Size

Approach charts have been criticized for a variety of reasons (Cox & Connor, 1987) but a common concern is the inability of pilots to easily read the information presented. A study by Welsh, Vaughan, and Rasmussen (1976) suggests that this concern is, in fact, real. They looked at the accuracy with which presbyopic subjects were able to read numerals of the same sizes (ranging from 1.2 mm to 2.3 mm) and typeface used on actual IAP charts. Font sizes used on NOS charts are shown in Figure 5-2. The subjects' task was to read numerals, cut from actual NOS and Jeppesen approach charts, that were presented by means of a rotating drum. Two lighting conditions were used, low luminance (1.0 ft. L) and high luminance (100 ft. L). Three levels of acuity were tested, using corrective lenses to compensate for the existing presbyopic condition. Corrective lenses were used to allow performance measures under 20/20, 20/40, and 20/60 visual conditions.

Although a number of important results were obtained, of greatest interest is the finding that subjects with 20/40 and 20/60 correction had great difficulty reading the numerals, especially as the size of the font decreased and under the low luminance condition. The authors concluded

Margin Identification uses a combination of 7 and 8 point, except for the name of the approach, which uses 14 point.

Text in the plan view is presented primarily in 7 and 8 point, with the exception of the inbound heading, which uses 9 point.

Text in the profile view is presented primarily in 7 and 8 point, with the exception of the inbound heading, which uses 9 point.

Text in the landing minimums is presented using a combination of 5, 7, and 8 point.

Text in the airport sketch is presented primarily in 5 and 7 point, with the exception of the airport elevation, which uses 8 point.

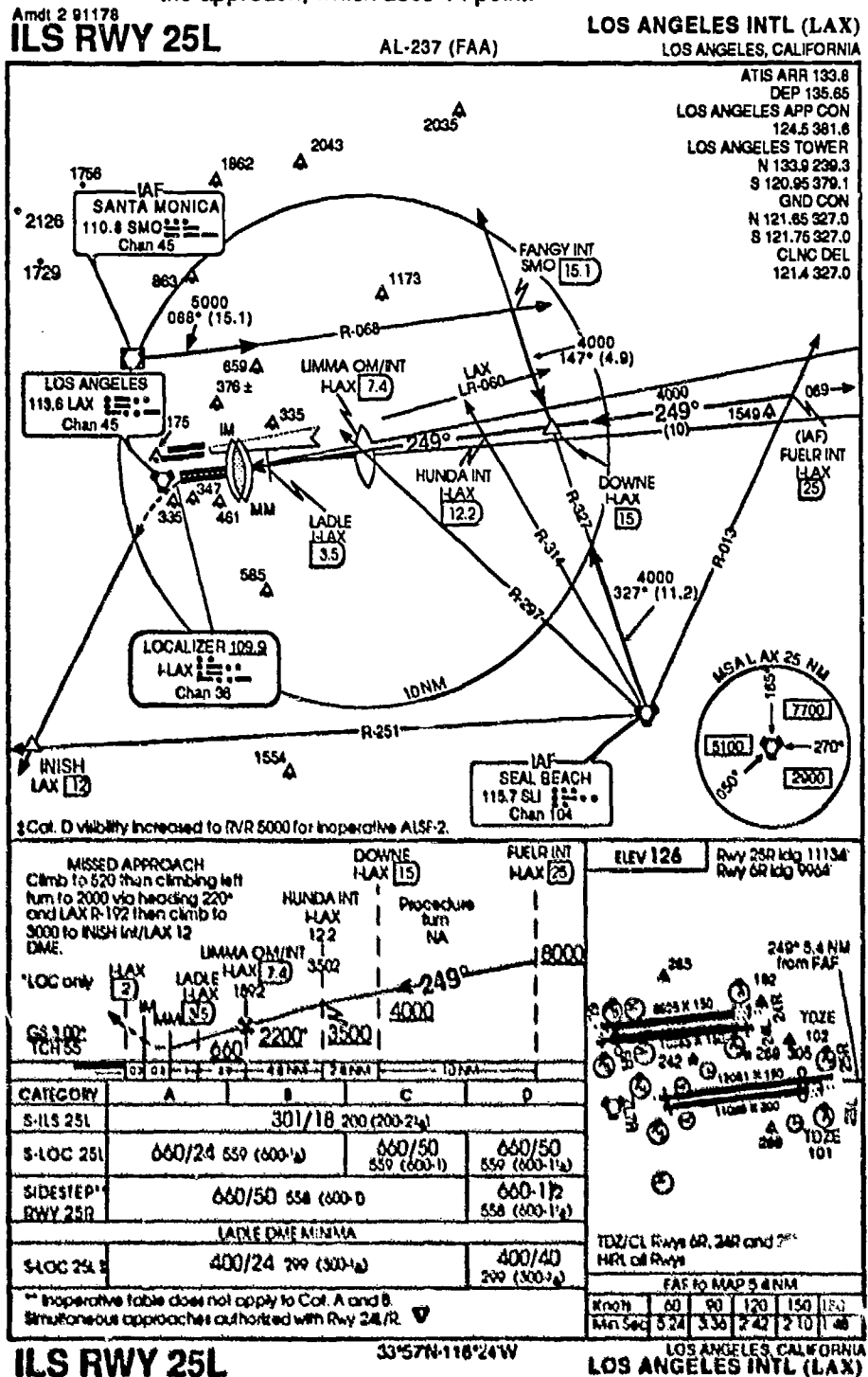


Figure 5-2. Font sizes used on NOS charts.

that "numerals on NOS and Jeppesen approach charts are inadequate for effective utilization by individuals with 20/60 near visual acuity. Individuals with 20/40 near visual acuity would also experience reading difficulty, especially under dim luminance conditions" (p. 1031). With less than 20/20 correction, luminance level and symbol size clearly impacted performance, to the point where under dim luminance and 20/60 correction, numerals were not readable. If this study were replicated under actual flight conditions involving vibration and extreme lighting conditions (producing washout or glare), it is quite possible that performance decrements would appear under the 20/20 conditions as well.

This study suggests that the issue of font size needs to be addressed. Unfortunately, it does not conclusively demonstrate the range of type sizes that should be used on IAP charts. Two limitations with this study restrict the types of conclusions that can be drawn. First, the task involved simply reading the numbers. Search was not required. In addition, this study did not assess the influence of vibration and other cockpit conditions on performance, although luminance level was a variable.

The obvious solution to improving the pilot's ability to find and read alphanumeric information is to simply increase the size of the type. However, this solution may be inappropriate for two reasons. First, serious space limitations on the chart mean that larger type sizes would have to be accommodated by reducing the amount of information that can be presented. For paper charts this could mean adding more pages and increasing the overall bulk of the charts that would have to be carried in the aircraft and the number of pages the pilot would have to access for a given approach.

Also, the eye is constrained by the size of type that can be efficiently read. Large type can reduce the ability of the eye to quickly recognize individual words. For example, Rehe (1974) argues that larger type sizes (defined as 14 point or above) allow fewer words to appear in the horizontal dimension, which inhibits effective use of peripheral vision in reading. Peripheral vision serves the role of preparing the cognitive system for the next set of words to be fixated, and this is thought to support efficient reading. Also, more fixations are required because, as type size increases, the number of words that fall into foveal view at any one time decreases, and, under some conditions, individual words may be read in sections thus disrupting the word recognition process (Tinker, 1946). Tinker and Rehe, however, are concerned with legibility of running text. It is not clear if there are similar negative effects of large print size when the task involves searching for names on a map.

The legibility literature includes a number of studies on font size. Application of the results of these studies is complicated by several factors, some of which have been mentioned before. An important complication of some studies is the failure to adequately define the actual size of the type being evaluated. Typefaces are usually defined in terms of a given point size, such as eight, ten, or 12 points, where a point is approximately 1/72 inch. However, point size is a remnant of the way type was measured when it was constructed as metal blocks (see Figure 5-3). The point size reflects the size of the metal block, not the character presented on that block. Since the typeface character may not span the entire length of this metal block, the actual size of the character itself can be smaller than its assigned point size. A typeface that fills the length of the block will have an actual size that is larger than a typeface that does not fill the length of the block, even though both are defined as having the same point size (Rehe, 1974). Although typefaces used today are no longer engraved on metal blocks, their dimensions have been preserved

in electronic form. Figure 5-4 demonstrates that typefaces with the same point size can radically differ in actual size.

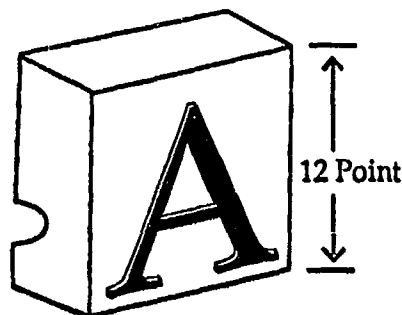


Figure 5-3. Measuring point size.

This is 12-point Bodoni. Even though it has the same point size as the Trump example below, it is actually smaller. Point size, alone, is not a good measure of type size.

This is 12-point Trump Mediaeval. Even though it has the same point size as the Bodoni example above, it is actually larger. Point size, alone, is not a good measure of type size.

Figure 5-4. Variations in actual size for typefaces having the same point size.

Rehe also emphasizes the importance of evaluating type size as a function of each typeface's x-height. The x-height of a typeface is the height of the body of a lower-case letter (see Figure 5-5). It is usually measured on the basis of the height of a lower-case x. Typefaces vary in the relative size of the body of the letter as compared to the ascenders. Figure 5-6 presents two common sans serif typefaces that differ in their x-height. In the Futura typeface, the lower-case letter bodies are approximately half the height of the uppercase letters, in contrast to the Helvetica typeface, where the lower-case letters are much higher. Typefaces with relatively large ascenders as compared to the body of the letter will be visually smaller than typefaces with letters that have relatively small ascenders and large bodies. To demonstrate that these differences are not always trivial, Poulton (1955) controlled for differences in x-height by optically reducing or enlarging different typefaces in order to produce the same x-height (1.6 millimeters). To accomplish this, Univers was reduced to 9.5 point size while Bembo was enlarged to 12 point. This means that when the x-heights are matched, the typefaces actually differed from each by 2.5 points. As Rehe (1974) points out, "some 8 point typefaces may appear as large as a 10 point size of a different type design, while some 10 point type sizes may consist of a relatively small type design, giving

it the appearance of a smaller size" (p. 27). Together, these factors complicate the comparison of user performance with different type sizes unless they are explicitly pointed out in the study.

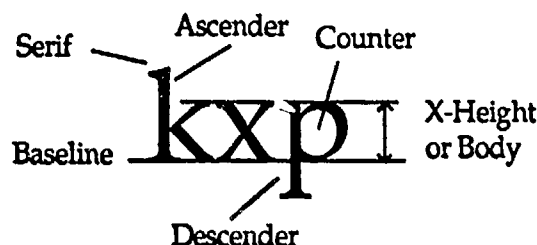


Figure 5-5. Some typographic terms.

This is 12-point Futura. Even though it has the same point size as the Helvetica example below, it appears smaller, in part, because of its lower x-height.

This is 12-point Helvetica. Even though it has the same point size as the Futura example above, it appears larger, in part, because of its larger x-height.

Figure 5-6. Perceived size due to x-height.

Recommendations for type sizes for general reading matter presented on paper usually include a range of from 9 to 12 points (e.g. Rehe, 1974; Tinker, 1963; Spencer, 1969). Rehe qualifies his recommendation by taking into account x-height. For a typeface with a small x-height, 11 or 12 point sizes should be used; for large x-height typefaces, a 9 or 10 point size is probably the best choice. These recommendations are interesting but their value to IAP chart use is unclear.

Recommendations have also been provided for type sizes to be used for textual material presented on electronic displays (e.g. Deutsche Institut fur Normungen, 1982; American National Institute for Standards, 1988; Snyder & Maddox, 1978; Shurtleff, 1980). Recommended minimum character heights range from 12 to 16 minutes of arc for visual angle, while preferred sizes (or sizes for critical information) vary from 18 to 22 minutes. These recommendations are intended for the office environment and their applicability to IAP charts is questionable.

Several studies have been conducted to assess the effect of type size on search in a map application. Phillips, Noyes, and Audley (1977) looked at how a number of type characteristics, including type size, affected searching for names on maps. They found that search was more efficient with 8 point type than 6 point, and concluded that, "if type is important, large point sizes are

justified, even though they may slightly reduce the legibility of other features on the map" (p. 680). They also found that type size requirements were influenced by the complexity of the map: Performance for 6 point type on easy maps was generally comparable to performance with 8 point type on difficult maps.

The Phillips et al. results are interesting but must be applied to the IAP chart situation with caution. First, the type of map used was not an IAP chart. In addition, the study employed an experimental environment that is not comparable to the widely varying luminance and vibration conditions of the cockpit. Finally, these results do not suggest an upper limit on type size.

Taylor (1975, cited by Taylor & Hopkin, 1975) investigated the legibility requirements of low altitude, high speed flight using charts presented on displays from film strips. He recommended that at a viewing distance of 19 inches, 8 point type (0.07 inch upper-case height) was the minimum character size for non-critical, familiar information. Critical information should be displayed using at least 12 point type (.11 inch). For a display distance of 19 inches, .11 inch characters translate into a size of approximately 20 minutes, which is consistent with the recommended character sizes described earlier.

Multer, Warner, Disario, and Huntley (1991) measured search performance for the inbound heading on NOS-based, fictitious IAP charts as a function of type size (9 point or 12 point). Search was significantly faster with the 12 point type. It is important to note that their study compared search times for headings in either 9 or 12 point type on charts where all other type was 9 point or smaller. Consequently, search may have been aided by type size coding. [The utility of type size coding is addressed in Section 7.3, "Information Coding Tools."]

The studies using search for information presented on maps clearly show that performance depends upon the font size used. Although the reading studies conclude that a range of sizes can be used for reading running text, the Multer et al. study suggests that important information should be presented using a font size at the high end of the range. That these sizes may be on the conservative side, especially with respect to electronic displays, is suggested by the type sizes to be used on B-777 displays. Boeing is designing their displays using three type sizes: 110, 167, and 224 mils (Weidemann, 1992). These type sizes, when converted to minutes of visual angle, translate into 20.4, 30.69, and 41.34 minutes at a viewing distance of 29 inches, when the following equation is used:

$$\text{visual angle} = 3438 \times \frac{\text{character height}}{\text{viewing distance}}$$

The smallest type size is used for familiar, unchanging information but there have been complaints from pilots evaluating the displays that this size is too small. This means that the 20 minutes visual angle proposed by Taylor (1975, cited by Taylor & Hopkin, 1975) is comparable to the smallest size used by Boeing. It should be noted that these character sizes are intended to support all of the displays to be used on the B-777. Consequently, the largest size may exceed what is required for IAP chart displays. Unfortunately, it is still not clear what text sizes are sufficient for the charting situation.

These findings suggest the following conclusion:

Increasing the size of type improves search performance for critical information at least up to the level of 12 point type or approximately 20 minutes of visual angle. It is not yet known whether increasing type size beyond this level will improve performance but there is some evidence to suggest that this is the smallest size that should be used for changing but non-critical information. Critical information should probably be presented using a larger type size, such as 14 point on paper or 30 minutes for electronic displays.

Although increasing the size of the type seems the most obvious approach to addressing the problem of pilots not being able to read an IAP chart, it is, in fact, only one tool that is available to the chart designer. Issues of typeface space efficiency, typeface weight, x-height, and other issues are equally important. These issues are addressed below.

5.3.3 Typeface Space Economy

Typefaces differ in how much horizontal space they require. Figure 5-7 presents the upper- and lowercase alphabets for two sans serif typeface, Helvetica and Futura. Futura clearly requires less space to convey the same number of characters. Because of the tight space constraints of IAP charts, one criterion for choosing a typeface is space economy. Greater space economy can be achieved by using a smaller type size but West (1990) argues that, in order to achieve greater legibility, "When space is at a premium it is better to choose a space-efficient typeface than to choose a smaller point size of a typeface that fits fewer characters on a line."

ABCDEFGHIJKLMNOPQRSTUVWXYZ (Helvetica)

ABCDEFGHIJKLMNOPQRSTUVWXYZ (Futura)

abcdefghijklmnopqrstuvwxyz (Helvetica)

abcdefghijklmnopqrstuvwxyz (Futura)

Figure 5-7. Differences in typeface space economy.

When choosing between typefaces, select the typeface that allows more characters per line.

In following this principle, it is important to consider potential conflicts with other typeface attributes, such as x-height (see Section 6.3.4.4). Typically, typefaces which are space efficient also possess relatively low x-heights. In this case, the requirement for high x-height should take precedence over space efficiency because of the critical requirement for legibility.

5.3.4 Type Proportions

Although studies have failed to demonstrate the superiority of one typeface over another, there are several aspects of typeface design that should be considered when selecting a typeface. Type proportions are a potentially important consideration, which are determined by four main factors (Carter, Day, & Meggs, 1985):

- Character stroke-to-height ratio
- Variation in stroke width
- Stroke width
- Ratio of x-height to overall letter height

5.3.4.1 CHARACTER STROKE-TO-HEIGHT RATIO.

The character stroke-to-height ratio refers to the ratio of the stroke width to capital letter height. This ratio affects the relative darkness of a typeface: A higher ratio means that the typeface will be darker in comparison to a typeface with a lower ratio. Most common typefaces used for printed materials have a ratio of approximately 1:10 (West, 1990). Since this ratio is the one with which we are most familiar, it is probably best to stay with this standard, especially in light of the lack of research on this issue.

The standard stroke-to-height ratio for typefaces used with paper is 1:10.

Taylor (1975, cited by Taylor & Hopkin, 1975) looked at the legibility requirements for low altitude, high speed flight charts that were presented on displays by means of film strips. For a viewing distance of 19 inches, he recommended a 1:6 ratio for 8 point type (0.07 inch upper-case height and a stroke width of .012 inch) and a 5.5:1 ratio for 12 point type (.11 inch upper-case height and stroke width of .02 inch). These recommendations are comparable to the 1:6 to 1:8 range suggested for electronic displays to be used in the office environment (e.g. American National Institute for Standards, 1988; Snyder & Maddox, 1978; Shurtleff, 1980).

For electronic media, stroke widths of between 1:6 and 1:8 are recommended.

5.3.4.2 VARIATION IN STROKE WIDTH.

In the discussion on serif versus sans serif typefaces (Section 5.3.1), reference was made to the issue of variation in stroke width, that is, the variation between the thickest and thinnest strokes of the letterform (see Figure 5-1). Many serif typefaces use hairline strokes as the thinnest stroke on the typeface. There is no evidence to suggest that large variations between thick and thin strokes contributes to legibility. However, hairline stroke widths can be difficult to see under low lighting conditions and when poor printing techniques are used. For this reason, it is best to use a typeface which has stroke widths of a similar width.

Avoid using a typeface that has large variations in stroke width.

5.3.4.3 STROKE WIDTH OR TYPEFACE WEIGHT.

Typeface weight refers to the relative darkness of a typeface, and can range from light type to black (see Figure 5-8). Type weight can be used as a tool in two ways. First, an appropriate weight can help to support sufficient contrast between print and background. In addition, variations in typeface weight can be used as a means of highlighting information. Only the first use is addressed here. See Section 7.2 for guidance on the use of typeface weight for information coding.

Helvetica Condensed offers four type weights. This is Helvetica Condensed Light. It has a slightly finer stroke than the other three versions of Helvetica Condensed.

Helvetica Condensed offers four type weights. This is Helvetica Condensed Regular. It has a slightly heavier stroke than Helvetica Condensed Light.

Helvetica Condensed offers four type weights. This is Helvetica Condensed Bold. This weight is typically used to highlight certain words or titles.

Helvetica Condensed offers four type weights. This is Helvetica Condensed Black. This Helvetica Condensed has a massive stroke and is used for titles, headers, and other attention-attracting information.

Figure 5-8. Four different weights for the same typeface, Helvetica Condensed.

Several studies have addressed the issue of what typeface weight is desirable. Although readers prefer a typeface that is almost bold in weight (Paterson & Tinker, 1940) and several authors have recommended the use of a semi-bold typeface (Roethlis, 1912; Lucklesh & Moss, 1940), these studies have failed to find a difference in performance (Paterson & Tinker, 1940). However, the results of studies performed under normal reading conditions may not apply to the unique conditions of the cockpit environment. Consequently, it is not possible to conclude whether a semi-bold typeface should be used. At best, it is possible to say that

The type weight used should support contrast between type and its background that is sufficient to allow accurate and efficient recognition of the information.

5.3.4.4 RATIO OF X-HEIGHT TO OVERALL LETTER HEIGHT.

The discussion on font size showed that typefaces of the same point size can differ radically in their x-height, the height of the body of a character (see Section 5.3.2 and Figure 5-6). Although no studies have been found that address the effect of x-height on performance, many graphic

designers (e.g. Collier & Cotton, 1989; West, 1990) recommend using typefaces with high x-heights as a means of improving legibility. Typefaces with high x-heights appear to be larger than typefaces with lower x-heights, thus making them easier to read. Until evidence to the contrary appears, the appropriate recommendation is

When choosing between typefaces, use the typeface with the higher x-height.

It should be mentioned, however, that this recommendation may conflict with the earlier recommendation to select the typeface that allows the greatest number of characters per line. Futura is preferred to Helvetica when the criterion is space economy while Helvetica is preferred to Futura in terms of x-height. Attempts to optimize on these conflicting criteria may mean that compromise is required on both. However, for reasons of legibility, the requirements of greater x-height must take precedence over space economy.

A possible solution to this conflict might be to use the condensed version of a typeface with a high x-height. Figure 5-9 shows the Helvetica typeface in condensed and regular versions. The condensed version is, in effect, a compression of the original typeface so as to make it more space economic. Although this would appear to offer a means for resolving the tradeoff between space economy and x-height, condensing the typeface can introduce distortion that makes the typeface more difficult to read. In addition, the individual characters may become more similar, making efficient discriminability more difficult. For these reasons, West (1990) recommends using a typeface that is inherently space economic rather than a condensed version of a typeface.

ABCDEFGHIJKLMNOPQRSTUVWXYZ (Helvetica Condensed)

ABCDEFGHIJKLMNOPQRSTUVWXYZ (Helvetica Regular)

abcdefghijklmnopqrstuvwxyz (Helvetica Condensed)

abcdefghijklmnopqrstuvwxyz (Helvetica Regular)

Figure 5-9. Condensed versus regular Helvetica.

5.3.5 Individual Character Confusions

A final concern in choosing a typeface is the discriminability of individual characters. Although this is technically not a tool, it is a concern of sufficient importance that should serve as an evaluation criterion when choosing a typeface. The ability to easily discriminate individual letters and numbers is crucial to accurate and efficient reading of IAP charts. Characters that have been found to be easily confused are shown in Table 5-2.

The extent to which individual characters are confused depends, in many cases, on the typeface. For example, Tinker (1928) concluded that character legibility is reduced when very thin, hairline

Confusable Letters	Source
fijlt	Cattell, 1885; Sanford, 1888; Vernon, 1931
Lowercase letter l, numeral 1, uppercase I	
a e	Vernon, 1931
o e	Vernon, 1931
B R	Tinker, 1928
G C O	Tinker, 1928
Q O	Tinker, 1928
M W	Tinker, 1928
F P	Spencer, 1969
H B	Spencer, 1969
V Y	Spencer, 1969
3 8	Spencer, 1969
T Y	Cakir, Hart, & Stewart (1980)
S 5	Cakir, Hart, & Stewart (1980)
I L	Cakir, Hart, & Stewart (1980)
K for X	Cakir, Hart, & Stewart (1980)
B for D	Cakir, Hart, & Stewart (1980)
M N for H	Cakir, Hart, & Stewart (1980)

Table 5-2. Confusable characters (continued next page).

Confusable Letters	Source
J T for I	Cakir, Hart, & Stewart (1980)
R for K	Cakir, Hart, & Stewart (1980)
Z for 2	Cakir, Hart, & Stewart (1980)
R S 8 for B	Cakir, Hart, & Stewart (1980)
0 O	Cakir, Hart, & Stewart (1980)

Table 5-2. Confusable characters, cont.

strokes are used in a typeface or when long or heavy serifs are used. Discriminability is improved when a character possesses distinctive ascenders or descenders, and when a large counter (the white space within a letter, such as e or p) is used (see Figure 5-5).

In addition, the individual characters of certain modern sans serif typefaces, such as Futura, Tempo, and Vogue, are constructed using a common set of modular elements. This means that individual characters may differ from each other on the basis of one or a few parts or modules. The result is a greater likelihood of confusion between characters (Degani, 1991).

Ovink (1938, cited by Spencer, 1969) provides some suggestions for improving the discriminability of certain characters. The English alphabet includes two characters that can appear in either of two very different forms: a or o and g or g. Using a tachistoscope, Ovink showed that "a" was more discriminable than "o," but either "g" or "g" was legible, so long as the flag on the g version was sufficiently large. Ovink also concluded that the dot on the letter i should be large and clearly separate from the stem, but its shape was not important. Finally, the hook on the letter "t" was found to be important for easy discriminability.

Other confusions between letters are possible, depending upon the typeface in question. Consequently it is important to

Ensure that all typeface characters are easily discriminable.

Avoid using a typeface that includes unusual letter shapes.

5.3.6 Type Case

Words set in all-caps are commonly used for headlines and other attention-attracting print situations. The question arises as to whether all-caps are, in fact, more legible than words set in lowercase letters with the first letter capitalized. One reason why all-caps could be more legible is their greater size relative to lower-case letters. Consequently, meaningful comparisons between uppercase and upper-/lowercase letters can only be made if the letters are the same height (see Figure 5-10).

ABCDEFGHIJKLMNOPQRSTUVWXYZ

abcdefghijklmnopqrstuvwxyz

ABCDEFGHIJKLMNOPQRSTUVWXYZ

Figure 5-10. Upper- versus lowercase letter discriminability.

In arguing for the greater readability of upper-/lowercase letters, Spencer (1969) concluded that "All-capital printing retards speed of reading to a greater extent than any other single typographic factor" (p. 30). This conclusion was based upon the results of studies by Breland and Breland (1944), Paterson and Tinker (1940; Tinker & Paterson, 1928), and Starch (1914). In each study, uppercase text was consistently read more slowly, reducing reading speed anywhere from 9.5 to 19% for five and ten minute test periods to 13.0% for 20 minute test periods.

Use of all uppercase letters also has the disadvantage that 40 to 50% more space is required than when upper-/lowercase letters are used (Spencer, 1969) and additional lines are likely to be required to handle the same amount of text. In addition, eye movement studies have shown that uppercase text increases both the duration of fixations and the number of fixations made, the latter due to the larger amount of space that must be scanned (Spencer, 1969). Many of these findings may very well be due to our unfamiliarity with uppercase letters. Rarely do we read material that has more than a few words in all uppercase.

Several authors have also argued that lowercase letters possess more distinctive shapes than do uppercase letters. Uppercase letters tend to resemble each other because they are based upon a more constrained range of shapes than lowercase letters. In contrast to the variety of shapes of words presented in lowercase letters, words in all-caps have a common boxlike appearance, which is likely to inhibit the speed with which words are recognized. This observation can be questioned, however, on the basis of studies which have shown that when very small lettering,

approaching the threshold of legibility, is required, uppercase letters are more easily discriminated (Poulton, 1964; Hailstone & Foster, 1967, cited by Spencer, 1969).

Although there is substantial data to suggest that upper/lowercase letters should be used, the fact that space is at a premium means that the greater discriminability of uppercase letters when very small type sizes are used must be considered. Fortunately, a study by Phillips, Noyes, and Audley (1977), which required subjects to search for names on a map, provides some clarification of these conflicting conclusions. They found that lower case names set with an initial capital were found 10 percent faster than names set in all caps.

Available research data suggests that upper/lowercase letter combinations are read more quickly and support more efficient search for names on a map than upper-case letters used without lower-case letters.

5.3.7 Inter-Character Spacing

Proper spacing between characters contributes to the speed with which textual materials are read. Inter-character spacing must be considered with respect to the spacing between characters within a word, and the spacing between words. Studies on reading suggest that experienced readers recognize entire words rather than using the individual characters to identify each word (e.g. Tinker, 1947; Underwood, 1985). The spacing between individual characters influences our ability to recognize the overall shape of the word comprised by those characters.

Figure 5-11 presents three sentences that vary in the spacing between characters. Tight spacing between characters results in the characters almost touching. In extreme cases, the characters actually do touch. Tight spacing makes the words look cramped, and makes them somewhat difficult to read. At the other extreme, widely spaced type hinders the reader's ability to differentiate the boundaries between words. Extra effort must be made to read the sentences.

This is an example of closely spaced type.

This is an example of the default spacing used a Macintosh page layout software package.

This is an example of widely spaced type.

Figure 5-11. Variations in spacing between letters.

Determining the correct spacing between individual characters can be difficult, in part because of variations in the appropriate spacing for certain character combinations. For example, the spacing used between AV must be different than that used between BL because of the unique qualities of the character shapes. The ANSI Human Factors Standard (1988) recommends that the spacing between characters be at least 10% of character height while the German Standard

(Deutsche Institut für Normung, 1982) suggests 15%. One possible reason for this discrepancy is that German words tend to have more characters (Osborne, personal communication, 1992).

Spacing will also be influenced by the typeface used. For example, West (1990) suggests that sans serif typefaces can be spaced more closely together than serif typefaces. Also, spacing depends upon the "openness" of the typeface. Openness is best judged by the roundness of the outside part of the "O." Open typefaces cannot be spaced as tightly as less open typefaces (West, 1990). Ultimately, however, character spacing will have to be assessed visually to ensure that the spacing looks consistent (West, 1990).

Spacing between characters within a word should be at least 10 to 15% but should be assessed visually to ensure that the spacing looks consistent for all combinations of word characters.

Spacing between words is also critical. Large gaps between words make it difficult for the eye to move smoothly from one word to the next. Tight spacing between lines of text, combined with loose spacing between words, can cause the eye to unintentionally skip from one line to the next. Tight spacing between words, on the other hand, obscures the boundaries between words. Typically, one character space is recommended for separating words (American National Institute for Standards, 1988).

Use one character space to separate words.

5.3.8 Leading

Although LAP charts do not contain large amounts of text, there are places where spacing between lines must be addressed, for example, for missed approach instructions. Leading refers to the spacing between lines of text. The term, leading, arose from the use of strips of lead to produce the selected spacing between lines of metal character blocks. Leading is important because it influences the ability of the eye to move smoothly along a line of text. If the spacing is too tight, the eye may accidentally shift from one line to another.

The amount of leading that should be used depends upon a number of factors, including the length of the text line and the character spacing used. Tight spacing between characters, together with short line lengths, requires the use of a tighter spacing between lines (West, 1990). The ANSI Human Factors Standard recommends that either a minimum of two stroke widths be used or 15% of the character height, whichever is greater. This space does not include the space required for lower case character descenders. Using the 15% of the character height as a starting point provides good spacing for the short lines of text used to display missed approach instructions. Once again, however, spacing should be checked visually to ensure that it looks consistent, especially when ascenders and descenders occur (West, 1990).

The spacing between bottom of descenders on one line and the top of ascenders on the next line should be approximately 15% of character height. The spacing should be visually assessed to ensure that it looks consistent.

5.3.9 Rotated Type

Most IAP charts align type in accordance with the direction of the symbols (e.g. radii) to which they are attached. Because we are not accustomed to reading words that deviate substantially from the horizontal, our ability to find and recognize words displayed in rotated type may be hindered. This view was substantiated in a study by Foster and Kirkland (1971, cited by Phillips & Noyes, 1977), which compared search times for names printed either as curved or straight print on two versions of a monochrome map. Not surprisingly, search for names printed in a horizontal orientation was significantly faster. The extent to which this affects performance in searching for names on IAP charts is not known. Consequently, it may be premature to conclude that text should never be rotated.

Whenever possible, avoid presenting text in a non-horizontal orientation.

5.3.10 Type/Background Contrast

In some cases, it may be necessary to apply type to a patterned background, for example, when a symbol label must be placed upon the dot-patterned symbol representing a body of water (see Figure 5-12). When this occurs, a loss of contrast between the type and the background pattern is inevitable. Consequently, it is important to ensure that sufficient contrast remains to support legibility. Unfortunately, data specifying the minimum contrast levels for this problem were not found in the literature.

An alternative is to present the label in a box against a plain background. There is some support for this approach. Shortridge (1979) looked at the differences in type size required to ensure that type size coding differences were consistently detected. As a part of this study, she investigated the effect of background on type size detection. She found that small differences in type size were harder to see when one or both of the labels were presented on a patterned background. Locating the labels within white boxes appeared to solve the problem. This conclusion is also supported in two studies on aviation charts, one study by Spiker, Rogers, and Cicinelli (1986), which looked at color coding on computer-generated topographic maps; and a second study by Taylor (1975, cited by Taylor & Hopkin, 1975) which investigated legibility on charts used for low altitude, high speed flight.

Discriminability of alphanumeric symbols which must be located on a patterned background may be improved by presenting that information in a box which has a non-patterned background.

5.4 SYMBOL CHARACTERISTICS TOOLS

Symbols are an important tool for embodying information on IAP charts. The term, "symbol," is used here to refer to visual elements other than alphanumeric characters. One advantage of using symbols is their greater compactness, in comparison to textual labels (Kolers, 1969; Zwaga & Boersema, 1983). A well-designed symbol is able to convey a lot of information in a relatively

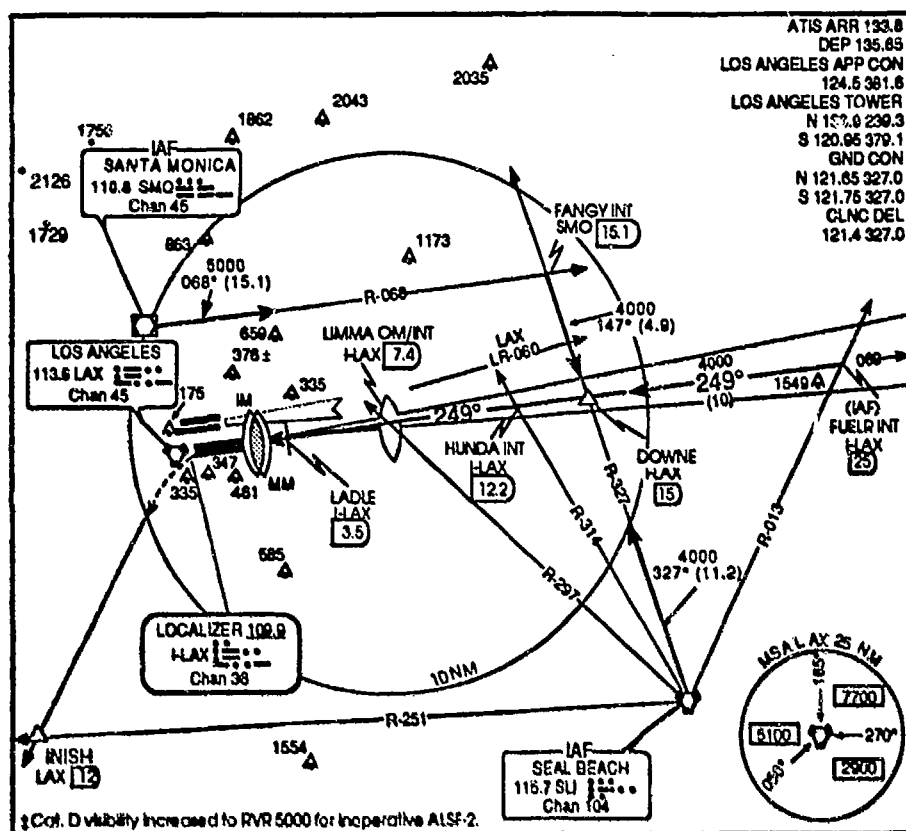


Figure 5-12. Loss of contrast between text and background on an NOS chart.

small space. In addition, symbols may be perceived more rapidly than reading text (Dewar, Ellis & Mundy, 1976; Ellis & Dewar, 1979; Walker, Nicolay & Stearns, 1965).

Symbol effectiveness depends upon a number of factors, including the chart user's ability to detect the symbol against a possibly cluttered background, discriminate it from all other symbols, and understand what it means. Ensuring that the symbols which are used are meaningful is a complex task that involves manipulating the visual elements of the symbol (shape, texture, size, etc.) so as to best support user understanding of the information to be conveyed by that symbol. Although this aspect of symbol design is critical to symbol effectiveness, it involves issues of a cognitive nature which fall outside the scope of this Handbook. Tools for making symbols easier to locate and discriminate from background visual elements and other symbols are addressed in the remainder of this chapter.

Designing effective symbols is not an easy task, nor is there much guidance available in the literature. There have even been claims that general principles for symbol design are not feasible: "Some researchers have attempted to provide guidelines for the use of certain symbol attributes...; others have focused on the development of performance-based criteria.... These approaches allow candidate symbol sets to be evaluated along predetermined dimensions. However, such general principles are often overridden by situationally specific factors. It seems more

fruitful to search for display principles that pertain to a restricted class of displays that will be used under similar circumstances" (Remington & Williams, 1986, p. 407).

Although this position is largely correct, it is still possible to provide some very general guidance on how to design discriminable symbols. This guidance, however, is intended for use *after* symbols that are thought to be meaningful and useful for IAP charts have been designed and evaluated for their ability to convey information. The information provided in this section will not compensate for symbols which lack basic meaningfulness.

Also, it is important to remember that discriminability is a relative concept (Easterby, 1970). It makes no sense to talk about the discriminability of a single symbol. A given symbol is discriminable only with respect to all other symbols likely to be used in the same context.

Three common types of symbols are used on IAP charts (Potash, 1977; see Figure 5-13):

- Point symbols, which specify a geographical location (e.g. waypoints and obstacles).
- Line symbols, which typically specify the direction of movement (e.g. the missed approach path symbol located at the end of the runway). Line symbols are also used to guide the eye from one location to another (see Chapter 5).
- Area symbols, which specify area in two dimensions (e.g. bodies of water).

Section 5.2 described two forms of control over eye movements made when searching for information on a chart. Symbols must be designed to support these control mechanisms in order to contribute to efficient symbol search. This means that each symbol must:

- *Be easily recognizable in foveal vision.* Its overall shape must be sufficiently simple and "clean" to allow rapid discrimination of the symbol from its background and neighboring visual elements.
- *Support processing by peripheral vision.* The efficiency of the search process is related to the extent to which peripheral vision can discriminate potential target elements from non-target elements. Although peripheral vision is not sensitive to detailed information, it can discriminate, with varying success, on the basis of color, size, shape and other visual dimensions. Symbols should be designed to support discrimination by peripheral vision, to the extent possible.

This section focuses primarily on how to design symbols which support efficient processing by foveal vision. Sections 7.2, "Information Highlighting," and 7.3, "Information Coding," suggest how symbols can be designed to support peripheral vision.

5.4.1 Symbol Shape

Easily discriminable symbols take advantage of certain "preferences" possessed by the visual system. Four types of preferences that will be looked at with respect to symbol shape are:

- Simplicity of shape
- Distinctive global shape

Simple, familiar symbol shapes should be used whenever possible.

Simple geometric shapes may also be combined to form more complex symbols. Regardless of whether geometric shapes are used alone or in combination, each shape should be designed to support maximum discriminability from all other shapes. Some guidance on how to do this is provided by Casperson (1950), who conducted a shape discriminability study to identify the parameters that contribute to more effective discrimination between simple geometric shapes. He found that each shape has its own dimension that best differentiates it. Shapes that were evaluated, together with their defining dimensions, are shown in Table 5-3.

Ellipses and triangles	Area
Rectangles and diamonds	Maximum dimension
Stars and crosses	Perimeter

Table 5-3. Optimal dimension for ensuring maximum discriminability of simple geometric shapes.

Ensure that each geometric shape is maximally distinctive by utilizing that shape's defining dimension.

5.4.1.2 DISTINCTIVE GLOBAL SHAPE

In her review of icon design for user-computer interfaces, Rogers (1989) argues that the overall global shape of the symbol appears to play the greatest role in symbol recognition and discrimination: "One way in which the shape of the icon [symbol] can facilitate easy discrimination among alternatives is to maximize the difference between the outline shape of the icons within a set. Hence varying the global structure of each of the icons should make it easier to locate and identify an individual icon [symbol]" (p. 144).

Her conclusion is based on a study by Arend, Muthig, and Wandmacher (1987; also see Pomerantz, 1983) which suggested that subjects can respond to the global features of an icon (e.g. shape, size, color) much more rapidly than the local features (the lines, elements, and structures within the figure) of an icon. If this is the case, icons which differ with respect to global features will be searched and identified faster than icons with similar global shapes but different local features. This hypothesis was confirmed by their results. The global shape of a symbol is an important tool for supporting both search and discriminability of symbols from each other and from background elements.

Clearly, there is a good deal of evidence to suggest that distinctiveness of the overall shape of the symbol is one of the most dominant factors that contribute to symbol search and recognition.

Symbols should be designed to have distinctive global shapes.

Distinctiveness also needs to be considered with respect to background information elements or symbols that may be positioned near to, or on top of, each other. Chapter 5 discussed various ways in which contrast between elements can be used to embody the visual structure of the chart. Contrast variations are made by varying the "weight" of the symbol (Henderson, 1976), that is, the extent to which a symbol stands out in comparison to other elements. Although the size or the line weight of the symbol can be varied, Henderson suggests that using variations in the ink ratio used to define a symbol is a more effective approach. A higher ink ratio will cause a symbol to appear to be brighter and, therefore, more important.

Regardless of the weight used, each symbol must support easy differentiation from neighboring and background information elements. This means that each symbol should possess a strong, outline contour that clearly defines the outline form of the symbol (Easterby, 1970).

Use a strong outline contour to define each symbol in accordance with its relative position within the visual structure of the chart.

5.4.1.3 SIMPLE LOCAL FEATURES

Although there appears to be strong agreement as to the importance of the global shape of a symbol, treatment of local features appears to be less clear-cut. For example, Rogers (1989) argues that distinctive local features are helpful as well: "The optimal solution, therefore, is to be able to design an icon set in which all the icons have different outline shapes but also contain sufficient local feature information for them to have a direct mapping to the underlying referents" (Rogers, 1989, p. 145). Clearly, Rogers is arguing for the importance of local detail as a means of conveying the meaning of a symbol. Other researchers, however, suggest that distinctive local features can reduce the discriminability of symbols and, in fact, Rogers seems to take this position as well when she suggests that the compact nature of symbols means that they should be as simple as possible: "[F]ine detail makes no contribution to unambiguous and rapid interpretation of pictorial information. Simple outline drawings of objects should be used in preference to drawings using shading" (Rogers, 1989, p. 145).

Some evidence which supports the view that local features of a symbol should not be emphasized is provided by Taylor (1975, cited by Taylor & Hopkin, 1975). In evaluating a set of symbols to be used on charts for low altitude, high speed flight, he found that all of the symbols were more effective than text labels, with one exception. The exception was a symbol for water towers which was "a detailed, fine line drawing" (Taylor & Hopkin, 1975, p. 201). The ineffectiveness of this symbol led Taylor and Hopkin to recommend that symbols should be bold and simple in form, avoiding the use of fine detail, especially if discriminability between symbols must take place by means of that detail.

Avoid using detailed local structure to define symbols. Instead, symbols should be discriminable on the basis of their global shape.

Avoidance of detailed local structure is also suggested by the recommendation by many researchers (Dudish & Goehler, 1988; Easterby, 1970; Forrest & Castner, 1985) that symbols should be filled rather than open. For example, Forrest and Castner found that "darker, more solid symbols" were found faster, and also were preferred by their subjects.

Use filled symbols rather than open symbols.

5.4.1.4 STRONG FIGURE/GROUND RELATIONSHIP

Symbol discriminability depends upon a strong figure/ground relationship that enables the symbol to stand out against a potentially cluttered background. Figure/ground relationships are determined by a number of factors, such as the simplicity and regularity of the item, and its relative brightness as compared to the background.

With respect to symbols, some tools for supporting figure/ground include:

- *Size*: smaller elements are more likely to appear as figures against larger elements.
- *Simplicity or familiarity of shape*: Simple or familiar shapes are more likely to be seen as figures.
- *Brightness*: Brighter elements (either through color or through a high ink-to-paper ratio) will tend to be seen as figures.
- *Continuous contour*: Closed shapes which are formed by a continuous line are likely to be seen as figures.
- *Strong contour*: A shape that is defined by a strong contoured line will tend to appear as a figure.
- *Interposition*: An element which has at least one surface that can be seen in its entirety will appear as being located "in front of" an element which has no surfaces that can be completely seen.
- *Symmetrical shape*: Elements that are symmetrical, especially around the left/right axis, tend to be seen as figures.

Ensure that each symbol stands out as a strong figure against all background patterns and elements.

5.4.2 Symbol Size

Unlike alphanumeric characters, there are no standard recommendations for symbol sizes. Probably the main reason for this is that minimum symbol size is going to depend upon the type of symbol being used. For example, an important location could be marked by using a simple dark square or by means of a pictograph that describes something about that location. Robinson and Sale (1969) recommend that symbols should have a minimum size of two minutes. Given

that the recommended sizes for alphanumeric characters range from 16 to 22 minutes, Robinson and Sale are probably referring to minimum size for a very simple symbol such as a square. Ultimately, symbol size must be determined by the size of the smallest component of a symbol that must be detected and recognized (Taylor & Hopkin, 1975).

There are other factors that must be considered as well. If colors are applied to the symbol or its background, legibility of the symbol may be reduced and must be compensated for by using a larger symbol (Dent, 1985). In addition, decisions about symbol size must take into account the desired size of a symbol. Certain shapes appear visually larger than other shapes, for example, round shapes seem larger than squares (Robinson, 1952). Also, a symbol that is located away from all other visual elements may appear larger than the same symbol located in a cluster of information elements (Potash, 1977). Each symbol should have a visual size that is appropriate relative to its role and position within the visual structure of the chart.

Finally, symbol size will be impacted by the realities of the chart. In some cases, a smaller size will have to be used in order to fit all the relevant information into the appropriate location (Potash, 1977). Clearly, selecting sizes for all symbols is not a simple task.

When making decisions about symbol size, consider all of the factors that impact symbol effectiveness, including legibility requirements, role and position of each symbol within the visual structure of the chart, apparent visual size, and space constraints.

5.4.3 Symbols and Color

With respect to symbols, color can be used in two basic ways. First, it can be used to add additional realism to a symbol. A second approach is to use it in accordance with a color coding scheme. The first use of color is addressed here. Color coding of symbols is discussed in Section 7.3.

Most users of electronic displays like color. For this reason, the temptation is to apply color to symbols to make them more realistic or attractive. The impact of color for added realism or attractiveness does not appear to have been studied. Consequently, the issue can only be addressed in terms of how performance might be affected. There are two obvious ways in which color might be expected to affect performance in finding and recognizing symbols. First, color might affect the legibility of the symbol. It is possible that the application of color might reduce the visibility of the borders of the symbol, making it more difficult to differentiate it from its background. The extent to which this is likely to be a problem is probably dependent upon the colors used for the symbol itself, any neighboring information elements, and the background against which the symbol appears.

A second way in which color might make a difference is as a potential source of distraction. Rogers (1989) argues against the use of color for added realism because the addition of color could slow the search process. This might occur not only because of reduced legibility but also because the eye may be attracted to certain colors, thus hindering its ability to move quickly from one element to another.

Of course, color could potentially compensate for reduced legibility in that, if the chart user knew the symbol's color, recognition could take place by means of color rather than shape (Easterby & Hakiel, cited by Collins, 1982). This use of color is addressed in Section 7.3 of the Handbook.

Color, used solely as a means of adding realism or attractiveness to symbols, should be avoided.

5.4.4 Achieving Symbol Legibility

Although symbols are used in a variety of everyday situations, we still don't know much about how to design them effectively. It remains for the chart designer to ensure that symbols are designed effectively so as to support efficient detection and discrimination of all symbols, regardless of how they may be positioned within a chart. Ultimately, good symbol design comes down to providing sufficient contrast between each symbol and its surroundings (Henderson, 1976). And there are no hard and fast rules on how to determine if sufficient contrast has been achieved.

Symbol legibility is also greatly impacted by the medium on which it is displayed. Consequently, care must be taken when transferring a symbol from the paper medium to electronic displays.

If a symbol that has been used on paper charts is to be transferred to the electronic medium, be sure to determine if sufficient resolution is available to support the symbol. Otherwise the symbol may have to be modified to take into account the reduced resolution of the electronic display.

Finally, all of this guidance on how to design legible symbols must be balanced by the need to provide *meaningful* symbols. A symbol that is easy to find and recognize must also effectively convey the information it is intended to represent.

5.5 SUMMARY

This chapter has addressed the issue of how to present alphanumeric and symbolic information so as to support the chart user's ability to quickly find and recognize those pieces of information of immediate interest. The focus has been on describing tools that can support rapid information access by enabling foveal vision to quickly discriminate the contours and details of the information from background clutter. In this way, the duration of each fixation can be reduced, resulting in faster search performance. As Section 5.2 pointed out, however, search performance can also be improved by utilizing the capabilities of peripheral vision in guiding the eye to those locations most likely to contain the information of interest. Tools for supporting peripheral vision are described in the next chapter.

6. SEARCH AND PERIPHERAL VISION

6.1 OVERVIEW OF CHAPTER 6

A major part of IAP chart use involves looking for specific types of information when they are needed. This process involves discriminating between the target information and all other information presented on the chart. Improving the ability of the chart user to distinguish target from non-target information would appear to contribute greatly to search efficiency.

This chapter reviews three types of design tools that may support this process:

- *Information Highlighting Tools*, which enable visual discrimination between important and less important types of information. Highlighting tools include bolding and reverse type.
- *Information Coding Tools*, which provide visual methods for categorizing information. These tools, which include type size coding and color coding, support perceptual rather than cognitive discrimination, thus potentially improving the search process.
- *Information Bounding Tools*, which can be used to visually separate chart elements by encouraging the eye to stay within these boundaries. Boxes and white spaces are examples of information bounding tools.

The first two types of tools are intended to help visual search by supporting peripheral vision. Highlighting and coding both embody information using visual tools that can be discriminated on the basis of peripheral vision. Consequently, the peripheral vision system can determine whether or not an information element is likely to be the target information on the basis of perceptual variables. If an element belongs to the same category (one category being importance), foveal vision can then be applied to analyze detail information to determine if the element is, in fact, the target item.

There is no hard and fast rule for discriminating between information highlighting and information coding. Highlighting is used here to differentiate with respect to the dimension of importance. Coding is intended for use in differentiating category membership. However, many of the same visual tools can be used for either purpose and importance is, obviously, one form of category membership. However, the distinction seems substantial enough and the limitations of one form versus another sufficiently clear to treat them as two separate phenomena.

Information bounding tools work in a slightly different way. Rather than distinguish on the basis of category membership, bounding tools help to prevent interference from neighboring items. Foveal vision tends to automatically process whatever information it finds, and has great difficulty ignoring information, even if it is irrelevant. If there are information items close to the item being fixated on, the visual system will attempt to process those items as well. This interference

from neighboring but irrelevant items slows down the processing of the fixated item. Consequently, one way of improving search performance is to provide sufficient separation between elements.

6.2 INFORMATION HIGHLIGHTING TOOLS

Information highlighting can be used in two ways. The educational community has investigated the value of highlighting as a tool for differentiating important information (general principles, major conclusions, etc.) from less important information (e.g. specific examples). Highlighting, in this case, is intended to help the reader focus on the important information so as to aid retention and support understanding of the material presented. This use of highlighting will not be addressed here. The other use of highlighting is to help the chart user find important information by manipulating the visual appearance of an item so as to attract the eye more rapidly. This approach would appear to be of benefit to the IAP chart situation. This section reviews the effectiveness of six methods of highlighting: brightness, bolding, reverse video, blinking, underlining, and boxing.

6.2.1 Highlighting through Brightness

One method for highlighting information on electronic displays is to make the important information brighter than less important information. Galitz (1989) feels that brightness coding has both a good attention-getting capability and is least disturbing to the user, as compared to other methods such as reverse video and blinking. For the IAP chart setting, its biggest limitation is that the user may not be able to detect the additional brightness under high levels of ambient illumination. In addition, when brightness variations are used under potentially poor viewing conditions, only two levels of brightness can be used (Van Cott & Kinkade, 1972). Similarly, brightness variations may not be discriminable on screens that lack sufficient contrast.

Brightness variations also suffer from the serious limitation that they may be more difficult to detect when applied to small information elements that may be distributed throughout the screen (Potash, 1977), as is the case with information elements on the plan view of the chart. One possible approach for solving this problem is to activate a double stroke or increase the line width when that element is highlighted (Weidenmann, 1992). Also, brightness coding is most effective when information elements are located near each other, making comparisons of relative brightness easier to perform.

<p>Under good viewing conditions, highlighting through brightness is both effective and not annoying to the user. However, its effectiveness is reduced under high ambient illumination levels, on low contrast displays, and when the highlighted elements are small.</p>
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6.2.2 Highlighting Through Bolding

Highlighting through bolding is, in a sense, the paper medium counterpart of highlighting through brightness. Like brightness highlighting, only two levels (bolded and non-bolded) can

be used. Also, this method is not annoying to the user. Unfortunately, three different studies using bolding of names on charts (Bartz, 1970b; Multer et al., 1991; Phillips, Noyes & Audley, 1977) failed to show that it is effective as a means for emphasizing important alphanumeric information during visual search. In each case, it was concluded that bolding did not support more efficient search but did contribute to chart clutter.

Bolding of important names does not appear to improve performance and should be avoided as it may contribute to chart clutter.

6.2.3 Highlighting Through Reverse Video

Reverse video is a common method of highlighting information on personal computers (Tullis, 1988). However, there is some evidence to suggest that reverse video may, in fact, hinder the search process. Galitz (1989) warns that overuse of reverse video can cause a crossword-puzzle effect, with "the haphazard arrangement of fields on the screen creating an image that somewhat resembles a typical crossword puzzle. An arrangement of elements might be created that tries to lead the eye in directions that the designer has not intended" (p. 95). Because reverse video stands out so radically, great care should be used in deciding what elements to portray in reverse video. Patterns are very apparent with this approach and if reverse video is applied to items from different categories, the user may infer unintended commonality between them.

Also, reverse video may reduce legibility of the information being highlighted. Gomberg (1985; cited by Fisher & Tan, 1989) found that search for information in reverse video was slower than search for non-highlighted information, a result that was confirmed by Fisher and Tan (1989). Because reverse video has good attention-getting capability (Galitz, 1989), reverse video may distract the eye when searching for information that is not highlighted but is presented on a screen where reverse video is used.

One study that did find improved performance using reverse video involved the use of search performance on IAP charts. Multer, Warner, Disario, and Huntley (1991) measured the time taken to identify the inbound heading on fictional IAP charts. Presenting the heading number in reverse video shortened the time required to identify the heading as compared to headings that were presented in bold or not highlighted. Although this study suggests that reverse video may be an effective tool for use in IAP charts, some of the subjects (who were pilots) expressed concern that the attention getting properties that made reverse video effective in this situation might prove distracting when searching for an item that is not highlighted. Also, some subjects felt that the heading was harder to read.

If reverse video is used, it is important to leave a margin around the highlighted information in order to avoid degraded legibility of characters located at the edge of the reverse video field (Galitz, 1989). In addition, legibility will be improved if a larger type size is used, combined with a sans serif typeface that has a heavier weight.

Reverse video is an effective means of attracting the user's attention but it can reduce the legibility of highlighted information. In addition, it may distract the eye when the target information is not highlighted.

6.2.4 Highlighting Through Blinking

Probably the most effective method for attracting the user's attention is blinking (Galitz, 1989). This effectiveness, however, is accompanied by a strong tendency for blinking to be distracting. It is very difficult for the eye to look at anything other than the blinking information. Blinking also can reduce legibility, for the simple reason that the highlighted information is displayed only momentarily before it disappears. Focusing on the blinking information can be difficult, especially for older eyes.

Finding the blinking information may also be delayed, depending upon the length of the off cycle (Fisher & Tan, 1989). Extending the duration of the "on" cycle and reducing the "off" cycle can help with this problem. Reduced legibility can also be avoided by using a method other than completely turning the message on and off. Two such methods are alternating between high and low brightness, and alternating between normal and reverse video (Tullis, 1988). Another approach is to use a separate blinking symbol that is located next to the message information which does not blink (Smith & Goodwin, 1972).

Of all the highlighting methods, blinking is the most annoying for the user if it is not used correctly (Tullis, 1988). Its use should be limited to situations where the highlighted information reflects a critical situation that demands an immediate response from the user (Galitz, 1989; Smith & Mosier, 1986). Also, only one blinking rate should be used (Poole, 1966, cited by Smith & Goodwin, 1971), and it is critical that the user be able to turn it off.

Highlighting through blinking should only be used to inform the user of a critical situation. For this reason, its use on IAP charts is probably not appropriate.

6.2.5 Highlighting Through Underlining

Underlining is a common method of highlighting when running text is used. Its ability to attract the eye, however, is limited and it may reduce legibility if the underline is positioned too closely to the underlined information (Galitz, 1989). Underlining may be effective as a means of highlighting a small amount of information relative to other information in a very confined section, although this is only speculation and has not been experimentally evaluated. If underlining is used, make sure that sufficient space separates the underline from the information being underlined.

Underlining is not a strong attention-getter but it may have limited utility as a way of highlighting a small amount of information that is located with other information in a restricted space.

6.2.6 Highlighting Through Boxing

Highlighting through boxing means placing important information within a box. In effect, this becomes a form of shape coding in that the eye can differentiate important from less important information on the basis of the box shape. Boxing might be expected to be a less effective form of

highlighting for two reasons. First, studies on shape coding (e.g. Williams, 1967) have shown that peripheral vision is less effective at differentiating items on the basis of shape than other visual manipulations, such as color and size. Also, the use of a box might hinder the ability of the eye to use the overall shape of the words or numerals enclosed in the box, thus slowing the recognition process. This does in fact happen, the severity depending upon the relative size of the letters within the box (Bridgeman & Wade, 1956). As the size of the letters within the box increased, letter recognition performance decreased.

One study that did investigate the effectiveness of boxing as a tool for highlighting did, in fact, show that performance with this method was worse than no highlighting at all (Gomberg, cited by Fisher & Tan, 1989). However, a study by Multer, Warner, Disario, and Huntley (1991) contradicts this result. They measured the time taken by pilots to find the inbound heading on an IAP chart. In one of their conditions, the heading number was placed within a box. Their results showed that performance in the boxing condition was superior to both bolding and no highlighting, and similar to reverse video. An explanation for these discrepant results is not obvious.

The relative benefits of highlighting through boxing are not clear. If boxing is used, be sure to use a box that is sufficiently large to support legibility of the information located within the box.

This form of boxing needs to be distinguished from other uses of boxes. Section 6.4 describes the value of boxing as a means of specifying spatial layout of chunks of information. This is a very different use of boxing which has proved to be very effective as a means of defining information spaces.

6.2.7 Limitations of Highlighting

Highlighting offers the advantage of enabling the chart user to quickly access information that has been defined as important. Certain forms of highlighting increase the rate at which highlighted information will be found. The disadvantage is that it can hinder the ability of the user to find information that is not highlighted (Fisher, Coury, Tengs & Duffy, 1989). This is a very real problem because the information needed by the user will vary depending upon the phase of flight, the user's personal information needs, and other factors.

Also, highlighting quite simply does not always work, a phenomenon Fisher and Tan (1989) refer to as the "highlighting paradox." They suggest that highlighting works only when users notice the time benefits of attending to the highlighted information. Otherwise, they may simply ignore the highlighting. In addition, they argue that the best method for highlighting is to use color, a method that will be discussed in Section 6.3. Based upon these findings they offer the following guidance on when to use highlighting.

- "As long as the level of highlighting validity [the extent to which highlighting is predictive] is greater than or equal to 50% [that is, at least half the time the target information is highlighted], and as long as only one option is highlighted, performance when color is used as the highlighting attribute should be at least as good as performance when none of the options is highlighted" (p. 28).

- "When the level of highlighting validity decreases below 50% or when the number of highlighted options is greater than one, highlighting may well be worse than no highlighting in ... displays that make it possible for subjects to process more than one option in a single fixation" (p. 28). It is not clear whether highlighting is better than no highlighting in these cases.

For these reasons, highlighting should not be used casually. Highlighting will probably prove to be more effective when applied to electronic media that possess the capability to vary the form of information presentation in response to user control. If the display "knows" what information is important to the user, on the basis of user input, highlighting may provide an effective tool for improving search efficiency. For paper charts and electronic displays that do not allow user control over what information is presented, highlighting is probably not a good choice.

Although highlighting can improve search efficiency for highlighted information, it may reduce efficiency for non-highlighted information. When deciding whether to use highlighting, strong consideration must be given to possible negative consequences that can arise through the use of highlighting.

If highlighting is used, it must be used conservatively in order to be effective (Tullis, 1988). Also, since its purpose is to emphasize important information, care must be taken in choosing those information elements that will be highlighted since non-highlighted information will be more difficult to find.

If the decision is made to use highlighting, it should be used conservatively and appropriately, in keeping with the information needs of the user.

6.3 INFORMATION CODING TOOLS

Highlighting methods are intended to support efficient search by using visual tools that attract the eye to information thought to be important. An alternative approach is to reduce the number of items that must be fixated before the target element is found by enabling peripheral vision to differentiate items that belong to the same category as the target information from items belonging to other categories. Foveal vision can then be applied to those elements possessing the target visual cue until the target element is located. This approach has the additional advantage that patterns of relationships between individual elements can be detected as well. In this way, the visual structure of the chart can be clarified through judicious use of coding techniques.

Because information coding achieves its advantage from the use of peripheral vision, coding methods must be based on visual cues to which peripheral vision is sensitive. Candidate codes are color, size, and shape. Each of these coding methods is described below.

6.3.1 Color Coding

The effectiveness of color coding has been investigated in a variety of experimental situations (see Christ, 1975, and Davidoff, 1988, for reviews). Although its positive impact on performance

has been clearly demonstrated in a number of situations, there is still some question as to the conditions under which color coding is effective. Color coding can be used in a variety of ways. Of interest are three purposes for which color coding might be used in the IAP chart setting:

- Color coding and display segmentation;
- Color coding to support search;
- Color coding to specify land surface heights.

6.3.1.1 COLOR CODING AND DISPLAY SEGMENTATION

A number of cartographers (e.g. Robinson & Sales, 1969; Taylor & Hopkin, 1975) have argued for the value of color coding as a tool for coping with the clutter problem on charts. For example, Taylor and Hopkin (1975) suggest that the solution to the clutter problem "must largely depend on judicious use of coding to reduce visual clutter and the apparent density of information, with emphasis on features according to their inter-relatedness and operational importance" (p. 203). In effect, it is argued that color can be used to segment information elements in accordance with shared category membership within the organizational logic of the chart.

Segmentation refers to the process, by the visual system, of determining what objects are presented, including the kinds of objects they are, and where they are located. The process of segmentation does not include *identifying* the segmented components. The value of color coding as a tool for display segmentation depends upon whether the segmentation that results corresponds to the segmentation required to perform the task. Luder and Barber (1984) suggest that display segmentation based on color can, under some conditions, be performed by the visual system by means of parallel processing. In effect, the visual system is able to quickly differentiate the various elements all at once, rather than having to look at each element in isolation.

Color segmentation happens before processing of other visual variables, such as shape, takes place. If the segmentation based on color does not correspond to the segmentation required by the task, color will serve as a distraction and degrade performance. It appears that the visual system is unable to inhibit unwanted processing of color attributes even if appropriate.

An example of this phenomenon is provided in a study by Macdonald and Cole (1988). Subjects were shown slides of horizontal situation indicators. On one task, the color, cyan, was applied to database waypoints, untuned nav aids, and airports. The waypoints comprised 70% of the cyan-colored items. The subjects' task was to count the number of waypoints to determine if the number presented on the display corresponded to the number they were told to expect. In this situation, color alone was not enough to perform the task accurately since shape had to be used to distinguish waypoints from the untuned nav aids and airports.

Performance on the colored display was not superior to performance without the use of color. In fact, when complex displays were used, where complexity was determined by the number of different types of information presented on the display, performance in the color condition was significantly worse. Subjects apparently had difficulty ignoring the color dimension and focusing only on shape. This study confirms Davidoff's (1988) conclusion that color is effective for display segmentation unless color causes an incorrect segmentation, in which case it may actually degrade performance.

This conclusion has also been confirmed in the case of information presented in tables. Arbitrary coloring of the rows or columns of a table is distracting and inhibits performance (Wright & Fox, 1970; Foster & Bruce, 1982), a result which can be expected since arbitrary use of color can attract the eye to non-target items (Davidoff, 1988).

Use color only if the display segmentation required by each task corresponds to the segmentation encouraged by the application of color.

6.3.1.2 COLOR CODING AND VISUAL SEARCH

Color coding to support faster search is probably the most established advantage of color coding. In his extensive review of the literature on color coding, Christ (1975) concludes that "[R]edundant colors can decrease search time for symbolic displays if the subject knows the color of the targets. This advantage of redundant colors increases as the density of the symbols in the display increases" (p. 561). A number of studies have shown that color coding helps to reduce the time needed to find a target item (e.g. Bundesen & Pedersen, 1983; Eriksen, 1952, 1953; Hitt, 1961). Color coding effectiveness in search tasks has also been demonstrated using maps (Christner & Ray, 1961; Shontz, Trumm & Williams, 1971). For the IAP chart situation, color coding used redundantly with shape coding may provide a way of improving search performance for types of information, such as waypoints and nav aids, presented on the plan section of the chart.

Color coding, used redundantly with another form of coding such as shape, improves performance when the task requires search. Its use may improve the performance of users searching for information elements located in the plan section of the chart.

Color coding is assumed to work in two ways in search tasks. First, it allows peripheral vision to differentiate same-category from different-category items. In addition, under some conditions, such as if the colors used are sufficiently distinguishable, parallel processing of color can occur (Carter, 1979). This result is suggested by the finding that increasing the number of items displayed from 30 to 60 increased search time on monochromatic displays by 108%, but only 17% for color displays. Parallel processing is less likely to occur as the similarity of the colors used increases, making them harder to discriminate (Carter, 1982; Farmer & Taylor, 1980). Color differences must be much larger than threshold in order to support parallel processing (Nagy & Sanchez, 1990; Nagy, Sanchez & Hughes, 1990).

Use of colors that are easily distinguishable can support nearly parallel processing of color.

Several studies have suggested that search time for color coded items is a function of the number of same-color items presented (Green & Anderson, 1956; Cahill & Carter, 1976; Smith, 1962). This conclusion is based on the finding of a linear increase in time as a function of the number of items sharing the target color. Variations in the number of items in non-target colors has much less effect on search performance, the effect ranging from small to none at all (Carter, 1979; Carter &

Cahill, 1979; Luder & Barber, 1984). Davidoff (1988) concludes that the impact of items in non-target colors depends upon whether targets have to be identified rather than simply detecting their presence.

The improvement in performance due to the use of color coding decreases as the number of items that share the same, target color increases. Performance is less affected by variations in the number of items with non-target colors.

An analysis of eye movements reinforces the view that the eye is able to ignore items having non-target colors. Williams (1967) looked at patterns of fixation during search for target two-digit numbers. He found that when target color was precued, fixations tended to be located on items sharing the target color. There was no tendency to look at any other specific color, suggesting that subjects were able to use color effectively. He also found that search time was substantially faster for color than for size alone, shape alone, or number alone.

Visual search time is also affected by the number of colors used on a display, with search times increasing as the number of colors displayed increases (Bundesen & Pederesen, 1983; Smith, 1962; Cahill & Carter, 1976). This reduction in performance appears to be smaller than that which occurs because of increases in number of same-color items. Consequently, it may be the case that it is better to use more colors for fewer items than fewer colors for more items. This conclusion needs to be tested, however.

Visual search times increase as the number of colors used increases.

In a study aimed at identifying the number of colors that should be used, Luria, Neri, and Jacobsen (1986) had subjects match a colored stimulus to one of a set of colors displayed on a CRT. They found that reaction time increased linearly as the number of colors used increased, up to a set size of five or six. As set size increased beyond this size, reaction times continued to increase linearly but less rapidly. Error rates, however, were found to increase sharply with set sizes of eight to ten colors. Cahill and Carter (1976) concluded that six is the maximum number of colors that should be used. Other researchers have argued that much larger numbers of colors can be used if the colors are sufficiently separated in color space (Smallman & Boynton, 1990). Potash recommends that eight or nine maximally saturated colors be the maximum number used if it is assumed that the chart user must remember what the colors mean. If the task is purely perceptual discrimination, a much larger number of colors can be used. It is unlikely that more than eight or nine colors will be needed on IAP charts if an intelligent color coding method is used.

Restrict the number of colors used to less than eight or nine if the user must remember what the colors mean.

The effectiveness of color is dependent on users knowing the target color. If they do not know it, performance is worse than when no color is used (Christ, 1975).

If the color is known in advance, performance will improve with the use of color.
If the color is not known, performance is worse than with no color.

Color also degrades performance when search is for a non-colored item on a display that includes color. This is one more piece of evidence suggesting that the visual system is unable to avoid processing color even if it hinders performance.

If search for non-colored items is required on a display where color is used, performance will be reduced.

Color is also effective when the target item has its own unique color. Macdonald and Cole (1988) found that searching for, and identifying, the active waypoint on a horizontal situation indicator was faster when the waypoint was colored magenta than when no color was used. This result is consistent with Christ's conclusion that "the most clear-cut finding is that if the color of a target is unique for that target, and if that color is known in advance, color aids both identification and searching" (pp. 106-107).

Color coding of a single item reduces the time needed to locate that item.

Color coding has also proved to be effective when searching for names on a map. Foster and Kirkland (1971, cited by Phillips, Noyes & Audley, 1977) used a map where land names were in black and water names in blue. When subjects knew the color of the name, search times were faster than in a map where all the names were printed in black, but when they did not know the color, the single color map was faster.

Color coding can improve search times for names presented on maps if the user knows the color to look for.

Color coding may not be effective when the task involves identification but not search. Identification tasks require the subject to identify an item, its condition, or value. This item is always located in the same place, which means that no search is required. Luder and Barber's (1984) subjects were asked specific questions about the status of a system based upon displayed information (e.g. "Valves 2 and 6 are closed"). They found that performance was worse when status was color coded (e.g. green for "open," blue for "closed," red for "emergency") than when no color was used. Shape coding was more effective than redundant color coding.

Color coding may not be effective and can degrade performance if the task requires identification but no search.

Even when performance is not improved by the use of color, there is a consistent finding that users prefer displays that use color (Christ, 1975; Tullis, 1981; Luder & Barber, 1984). This preference may even affect the subject's confidence when time-sharing between two tasks. Luder and Barber (1984) found that subjects performing a tracking task and a secondary task (either search

or identification) were superior on the tracking task when the secondary task used a color coded display. "Evidently, simple awareness that essential displays are redundantly color coded is sufficient to make more processing resources available to the flying task, even at times when the operator's attention is not diverted away to other displays" (p. 29).

Users like color and it may improve their performance in dual-task situations.

6.3.1.3 COLOR CODING LAND SURFACE HEIGHTS

One of the concerns often expressed about IAP charts is their failure to adequately provide information about terrain heights (Cox & Conner, 1987; Friend, 1988). Whether IAP charts should provide terrain height information is outside the scope of this document. However, it may be appropriate to briefly review some studies which have looked at how best to portray land surface information.

Color is an effective tool for supporting figure/ground discrimination (Poulton & Edwards, 1977). In addition, it is able to specify commonality between areas located in diverse parts of a display. For these reasons, color is a potentially useful means of specifying terrain heights.

The most common method for conveying land surface heights on topographical maps is by means of height contour lines (Eley, 1987). Contour lines are sometimes supplemented by color-layering, which involves shading areas of a particular height interval with a color or tint (Eley, 1987). Color-layering is assumed to support more effective visualization of surface heights. Several studies have been performed by Phillips and his colleagues to assess this assumption.

Phillips, DeLucia, and Skelton (1975) had 16- to 18-year-old subjects perform two different types of tasks using a variety of types of contour maps. The tasks varied in two respects: whether relative or absolute height was required, and the degree to which landscape visualization was required. Landscape visibility was assumed to be required in order to differentiate "areas of high ground; determine visibility of specified features from a given viewpoint; locate areas of steepest slope; match cross-section profiles; match map portions to relief models" (Eley, 1987, p. 655). Types of maps that were used included: plain contour maps, hill-shaded contour maps, color-layered contour maps, and digital spot-height maps. When relative height was sufficient and visualization was required, performance on the color-layered maps was superior to the other types of maps (also see Eley, 1987). However, judgments of absolute height using color-layered maps were not as good, which the authors suggested might be due to difficulty in matching the tints to the key.

Two important, general conclusions appear in this study. First, the best method for specifying terrain heights is clearly dependent upon the nature of the task. It is not possible to say that one method is always best. Second, the differences in performance across the different maps is substantial. "On many of the questions the difference between the lowest and highest scores exceeds fifty percent. In real life this means that a map reader with an appropriate map [appropriate for the specific task] may be fifty percent faster or fifty percent more accurate than someone with an inappropriate map" (Phillips, DeLucia & Skelton, 1975, p. 45).

The superiority of contour maps over spot heights for tasks requiring only relative height judgments was supported in a study by Kuchar and Hansman (1991). Pilots flew instrument approaches in a flight simulator using an approach plate presented on an electronic display. During the approach, ATC issued a clearance that included a vector into low terrain. Recognition of the terrain hazard occurred more frequently with the contour maps (78%) than with spot elevation maps (50%). In a survey conducted after the approaches, pilots unanimously preferred the contour maps.

Phillips (1982) compared the performance of 13- to 15-year-old subjects on two types of color-layered maps, one type which was monochromatic and used different tints, the second which used different colors. For relative height judgments, monochromatic layering was slightly superior to the color maps.

Color is an effective tool for supporting map users' abilities to judge relative heights and visualize the terrain. Monochromatic coding methods, however, may be just as effective.

Together, these studies suggest that color-layering improves the readability of contour maps. However, the types of tasks evaluated do not necessarily reflect the types of uses a contour map is put to by an IAP chart user. Eley (1987) suggests that a fundamental task involved in using a contour map is comparing the map to the viewed land surface. This task is obviously critical to the IAP chart situation. A better understanding of the types of information needed by the IAP chart user should be obtained before deciding how to embody land surface height information.

A better understanding of the IAP chart user's needs should be obtained before choosing a method for embodying land surface height information.

6.3.1.4 LIMITATIONS ON COLOR CODING

In deciding whether to use color, several factors should be considered. First is the problem of color blindness. Also, the lighting conditions in aircraft at night can affect the displayed color as will the use of red lighting (Potash, 1977). Very low levels of illumination can wash out certain hues while red lighting can cause some colors to disappear or make them appear to be gray. Finally, the colors that actually appear on the display can be greatly affected by the method used to generate those colors (Taylor, 1975, cited by Dudish & Goehler, 1988).

If the decision is made to use color, many of these problems can be handled through careful selection of colors and by always using color redundantly with other coding schemes, such as shape. The next section talks briefly about criteria for color selection.

If color is used, take into consideration these problems of color use when selecting colors and always use color redundantly with other coding schemes, such as shape.

6.3.1.5 COLORS TO USE

Currently, there is no standardization of color meanings in the cartographic environment. In fact, there is very little agreement as to which colors to use as Table 6-1 demonstrates. This table lists two sets of recommended color assignments. The first column presents the standardized colors to be used on military topographic maps, as specified by the Army Field Manual 21-31 (cited by Potash, 1977). The second column lists the colors determined by Spiker, Rogers, and Cicinelli (1986) to be most appropriate for computer-generated topographic maps intended for low level and nap-of-the-earth flight. Clearly, there is little consistency between them.

Although specific color recommendations cannot be made, it is possible to provide some guidance on color selection. Because color selection is a very complicated process, only the more important factors will be addressed.

	Army	Spiker et al.
Black	Cultural or manmade elements	Contour lines
Blue	Water	Open water
Green	Vegetation	Railway lines, obstacles
Brown	Relief features such as contours	
Red	Roads, built up areas, and special features.	Enemy point symbols and tactical overlay
White		Friendly point symbols and tactical overlay
Yellow		Cultural features, bridges
Magenta		Cities, aeronautical data
Pink		Roads
Cyan		Streams
Aqua		Forested terrain
Gray		Non-forested terrain

Table 6-1. Two examples of recommended colors for topographic maps.

Color blindness in males is a serious concern that must be considered in selecting colors. Table 6-2 lists nine colors that Van Cott and Kinkade (1972) suggest can be recognized by both color-sighted and color-blind people.

Red	Gray
Orange	Buff
Yellow	White
Blue	Black
Purple	

Table 6-2. Colors that can be used by color-blind users
(from Van Cott & Kinkade, 1972).

The issue of red light in the cockpit is a second important concern. Its impact on color selection in the past is described by Taylor and Hopkin (1975). "Map colors have been restricted to the short wavelengths (purples, blues and greens) and to colors with large grey/black components. These do not disappear against white backgrounds under red light, as do reds, oranges and yellows, but appear as shades of grey as the map assumes a monochromatic appearance" (p. 202). Clearly, color selection is heavily restricted by the need to consider red light use. Taylor and Hopkin argue, however, that red light use is rapidly diminishing and should not influence color selection for charts.

Color selection is also hindered by interactions between colors. Perceived color is affected by brightness: a gray area positioned on a dark background appears lighter than the same gray area on a light background (Potash, 1977). Complementary or near complementary colors located near each other enhance the perceived intensity of both colors. Very small areas of color suffer a loss of brightness and saturation while opposite effects occur with large areas. For example, colors with a similar hue, such as blue and green, may be indistinguishable (Wood, 1968). This can also occur under high ambient light levels (ARP 4032).

Overlaying colors may alter the hue of the original colors. For example, using layer tints on top of shaded relief can cause both colors to appear darker than if each color were presented against a white background (Potash, 1977).

Finally, it is important to consider possible differences in apparent line width and brightness that can occur when color is applied. Adjustments may have to be made to compensate for certain colors appearing brighter or producing a wider line.

When selecting colors, take into account the range of ambient illumination levels that will occur, the limitations of the system used to generate the colors, the sizes of the areas to which the colors will be applied, and unexpected effects due to presenting combinations of colors.

Several studies have evaluated the effect of color on legibility of text. Table 6-3 shows the color combinations recommended by Bruce and Foster (1982). The first column lists the color used for presenting the text. The second and third columns list background colors that can be used with the text color listed in the first column or should be avoided as a background color. Colors in parentheses are less desirable choices. Pastoor (1990) takes a very different approach. He concludes that "any desaturated color combination appears to be satisfactory for text presentation" (p. 157). Travis, Bowles, Seton, and Peppe (1990) concur with Pastoor, adding the caveat that the color combination must maintain a luminance contrast modulation of 50%.

Character Color	Colors to Avoid	Colors to Use
White	Yellow	Magenta, red, green, blue
Yellow	White, cyan	Blue, (red), (magenta)
Cyan	Green, yellow	Blue, (white), red
Green	Cyan, blue	Yellow, white, (red), (magenta)
Magenta	Red	Blue, white, (cyan), (green)
Red	Magenta	White, yellow, cyan, green
Blue		White, (yellow), (cyan), (green)

Table 6-3. Bruce and Foster's (1982) recommendations on text/background color combinations.

Colored text legibility can also be improved through the use of a method called *haloing* (Weidemann, 1992). Outlining colored text with black helps the text to better stand out and improve readability.

ARP 4032 recommends six colors for use in the cockpit environment: white, red, green, yellow (or amber), magenta (or purple), and cyan (or aqua). Black, gray, brown, and blue are recommended as background colors. Also recommended is the use of red and yellow (or amber) only as warning or caution signals.

Choice of a color coding scheme should also take into account the color schemes used by other displays in advanced automation cockpits, such as the horizontal situation indicator. Table 6-4 lists two color coding schemes recommended in Advisory Circular 25-11. These color recommendations are based upon two coding methods currently used in airline displays. The advantage of following one of these methods is twofold: Consistency will help the user learn and remember the scheme, and will help to prevent confusion when comparing information across displays.

Warnings	Red
Flight envelope and system limits	Red
Cautions, abnormal sources	Amber/Yellow
Earth	Tan/Brown
Scales and associated figures	White
Engaged modes	Green
Sky	Cyan/Blue
ILS deviation pointer	Magenta
Flight director bar	Magenta/Green

	Color Set 1	Color Set 2
Fixed reference symbols	White	Yellow*
Current data, values	White	Green
Armed modes	White	Cyan
Selected data, values	Green	Cyan
Selected heading	Magenta**	Cyan
Active route/flight plan	Magenta	White

* "The extensive use of the color yellow for other than caution/abnormal information is discouraged" (AC 25-11, 1987, p. 11).

** "In color set 1, magenta is intended to be associated with those analog parameters that constitute 'fly to' or 'keep centered' type of information (AC 25-11, 1987, p. 11).

Precipitation and turbulence color codes:

Precipitation	0 - 1 mm/hr	Black
	1 - 4 mm/hr	Green
	4 - 12 mm/hr	Amber/Yellow
	12 - 50 mm/hr	Red
	Above 50 mm/hr	Magenta
Turbulence		White or Magenta

Background color (gray or other shade)	Background color may be used to enhance display presentation
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Table 6-4. Advisory Circular 25-11 color coding schemes.

Any color coding scheme should be evaluated to assess the potential for confusion or misunderstanding due to inconsistency with existing color coding schemes.

Use a color coding scheme that is consistent with other displays in the cockpit.

6.3.2 Size Coding

A second approach for coding category membership is by means of size. Using a search task, Williams (1967) varied the size of symbols from approximately 0.8 degrees to 2.8 degrees in visual extent. Size was more effective than shape but less effective than color. He also found that size coding was most effective for the largest targets. Eye movement patterns showed that there was a tendency to look at targets that were similar to the target size, suggesting that peripheral vision was able to discriminate on the basis of size, at least to some extent.

Size coding has been shown to be especially effective as a tool for coding hierarchical differences in names. Bartz (1970) found that search was faster when the subject knew the size of the target on maps using a number of sizes. If the size of the target was not known, the single size map produced faster performance. Shortridge (1979) investigated differences in letter sizes that should be used to ensure that the user can easily distinguish size categories. She found that a size difference of 34% or greater between two letter sizes resulted in at least 85% correct performance. Ten point type is approximately 34% larger than 7.5 point type. Size differences of 17 to 22 percent are only partially discriminable while size differences of less than 15% (e.g. 7.5 point versus 8.5 point) were not distinguishable. She concluded that "The cartographer may safely use any combination of sizes that represents a 2 to 2.5 point size difference or approximately a .020 inch increment when working within the range of sizes used in this experiment (5.5 point to 15 point lettering or .041 to .131 inch in capital letter height). The larger differences are especially important when names are placed over textured backgrounds (e.g. the dot patterns representing bodies of water)" (p. 20).

6.3.3 Shape Coding

When compared with color and size coding, shape coding is the least effective (e.g. Williams, 1967). However, in the IAP chart situation, shape coding is still necessary and should always be used redundantly if other coding methods are employed.

Shape is a necessary coding method in the IAP chart situation and should always be used redundantly if other coding methods are employed.

This principle applies even though there is conflicting evidence as to the value of redundant coding. Some researchers (e.g. Eriksen, 1953; De Brailles, cited by Forrest & Castner, 1985) have found that redundant coding improves search performance. Based upon these studies, Robinson and Sales (1969) conclude that "The visual variables are additive in that if two marks are varied in two ways (e.g., in both shape and size), the contrast between them will be greater than if only one variable had been modulated. Variation of only one variable may be sufficient to achieve the needed contrast if the mark is simple, but the more complex the mark, the larger the number of elements that must be varied to obtain contrast" (Robinson & Sales, 1969, p. 285).

Other researchers, however, conclude that the user will attend to only one dimension. "When multiple information about a target is known, one stimulus dimension is generally used, with the remaining information being discarded during acquisition" (Williams, 1971, p. 33). The relative merits of redundancy remains an open issue, the exception being that shape coding should always be used in combination with color coding.

6.4 INFORMATION BOUNDING TOOLS

Information highlighting and information coding share the objective of reducing the number of items that must be fixated before the target information is located. Information bounding tools offer a different approach to supporting peripheral vision by using graphic tools to guide the eye's movement through space. These tools can be used in an almost infinite number of ways. This section looks at methods relating to three objectives:

- Reducing the amount of space to be searched;
- Information bounding and the use of columns;
- Reducing inter-item interference.

6.4.1 Reducing the Amount of Space To Be Searched

Finding a specific information element, such as a name, can be a time-consuming process. Phillips, Noyes, and Audley (1978; also see Phillips & Noyes, 1977) suggest that one way of reducing search time for names is to restrict the amount of space that must be searched. For example, the size of the grid system used on street maps is a critical factor in that the larger the section, the greater the candidate space in which a street name is located. Search can be greatly improved by providing a system that allows the chart user to quickly find the target space, which should be sufficiently small to require search of only a few potential targets.

It is not the amount of space that must be searched which slows the process, but, rather, the number of items that could potentially be the target (e.g. Lloyd, 1988). "First, the dominant effect on search time is the number of elements to be searched. It matters relatively little if the elements are closely spaced, requiring little scanning, or are widely dispersed. The increased scanning that is required with wide dispersal does increase search time slightly. However, the high density of nontarget elements when the items are closely spaced also has a small retarding influence on search. Thus the two factors, scanning and visual clutter, essentially trade off with each other as target dispersion is varied" (Wickens, 1984, cited by Lloyd, 1988, pp. 370, 372).

The user needs support in identifying that part of the chart likely to contain the target item, especially if the user is dealing with an unfamiliar geographical location. A simple organizational structure that helps the user to orient and develop expectations as to where chart information elements are located in actual geographical space could contribute considerably to improving the search process. This structure must then be complemented by controlling the density of symbols in any one part of the chart (Phillips & Noyes, 1982).

Providing an organizational structure to help the chart user orient, combined with control over the density of symbols in any one part of the chart, will contribute to efficient visual search.

6.4.2 Information Bounding and the Use of Columns

A large proportion of the guidance information in this Handbook has addressed the question of how to support visual search through the plan section of the chart. The topographic format is only one of a variety of formats used on a chart (see Section 5.2). Search for alphanumeric information in non-topographical layouts is just as common.

Searching for one particular text element positioned within a cluster of elements can be a time-consuming process which is also prone to error. A number of studies have been performed using the types of screens likely to be found in the office environment (see Tullis, 1988, for a review). The outcome of many of these studies suggests that columns are a very effective tool for reducing screen complexity and clutter. This section describes the application of columns to IAP charts.

Pulat and Nwankwo (1987) investigated the complexity of screens for displaying database records. They found that the time required by subjects to copy a database record from the screen onto a piece of paper, not surprisingly, depended upon the complexity of the record layout. Of interest, though, was their finding that complexity was a function of the extent to which the layout deviated from a column arrangement. Tullis (1981) also showed that the column arrangement improved performance, as measured by rate of data entry.

The benefits of columns arise from their simplicity and the predictability of space layout they offer. This benefit apparently is greatest for vertical formats. Parkinson, Sisson, and Snowberry (1985) found that search times were fastest for words arranged in columns rather than rows, even though adjacent columns had more space between them than the rows. Apparently, the eye is better able to scan vertically than laterally.

Search performance appears to be faster for items arranged in columns rather than rows.

These findings are consistent with the results of a study by Multer, Warner, Disario, and Huntley (1991) which looked at search times for radio frequencies. Three layouts that were used resembled charts produced by NOAA, Jeppesen Sanderson, Inc., and the Canadian Department of Energy, Mines and Resources. The fourth layout presented the radio frequencies in a two-column layout. Parts of these layouts are shown in Figure 6-1. The two-column layout produced faster searches than the NOS and Jeppesen charts but comparable performance to the Canadian layout. Especially interesting is the superiority of the column format over the Jeppesen layout. The only difference between the two is the strong vertical boundary provided by placing the radio frequencies in their own column. Apparently, the eye is able to use the boundary provided by consistent left justification of the frequencies to great effect, even though the distance between the radio frequency name and the frequency itself has increased.

There is also evidence to suggest that the size of the columns used affects search performance. Tullis (1984, cited by Tullis, 1988) found that the time needed to find a target item was determined by two factors, the number of groups of characters that had to be searched and the size of the group. Search time increased as the number of groups increased and also as the number of items per group increased. In addition, the optimal size of the group appears to be no larger than

ISLIP APP CON
 120.5 367.2
 ISLIP TOWER
 119.3 233.2
 GND CON
 121.7
 CLNC DEL
 121.85
 ATIS
 128.45
 RADIO
 122.6
 CTAF
 119.3

(a) NOS layout.

ISLIP APP CON 120.5 367.2
 ISLIP TOWER 119.3 233.2
 GND CON 121.7
 CLNC DEL 121.85
 ATIS 128.45
 RADIO 122.6
 CTAF 119.3

(b) Jeppesen layout.

ISLIP APP CON 120.5 367.2	ISLIP TOWER 119.3 233.2	GND CON 121.7	CLNC DEL 121.85	ATIS 128.45	RADIO 122.6	CTAF 119.3
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(c) Canadian Department of Energy, Mines and Resources layout.

ISLIP APP CON	120.5 367.2
ISLIP TOWER	119.3 233.2
GND CON	121.7
CLNC DEL	121.85
ATIS	128.45
RADIO	122.6
CTAF	119.3

(d) Multer, Warner, Disario and Huntley layout.

Figure 6-1. Four alternative radio frequency layouts (from Multer et al., 1991).

five degrees. "These results indicate that some aspect of the user's processing of the screen changes when the average size of the groups gets larger than 5 degrees. It appears that a screen with groups no larger than 5 degrees can be scanned more efficiently than one with larger groups" (Tullis, 1988, p. 389). The five-degree figure appears to define the size of a group that can be fixated as a whole, without the need for scanning. Once the group size surpasses the five-degree figure, multiple fixations are required, and visual search time increases accordingly.

Column sizes of five degrees or less appear to support the most effective search.

The Multer et al. (1991) study is interesting in that it demonstrated similar search performance when information was presented in columns as in separate boxes. It would appear that the use of white space to clearly separate individual information elements or element clusters is the common factor. This hypothesis is supported by studies which have shown that the use of graphic lines for defining information spaces does not impact performance. For example, Thacker and Babu (1988) compared search times for items located in tables that differed only as to whether graphic lines separated the rows. No difference in performance occurred. Whether this finding holds up when the table is positioned within a very dense background, such as on an IAP chart, is unknown. Consequently, it seems premature to discard the graphic lines.

Graphic boundaries don't appear to affect performance either positively or negatively. It may be premature to discard the graphic lines, however.

A familiar form of a column arrangement is the table. Tables are used on current NOS charts and the question arises as to how information bounding tools might be used to support more efficient access to the information stored in a table. Emurian and Seborg (1990) measured the time taken for subjects to detect a target located within a table. Six types of tables were used. Two of the tables varied the spacing between the columns, two varied the spacing between rows, and the final two looked at spacing variations for diagonal tables. Their results clearly showed that tight spacing produced the best performance, except for the diagonal tables. This result is interesting because it contradicts the assumption that tightly packed tables might suffer from interference due to neighboring items.

It would appear that search for information stored in tables is not aided by increasing the spacing between table elements.

6.4.3 Reducing Inter-item Interference

One of the more important uses of white space is as a means of reducing interference between neighboring information elements. When fixating an item, the visual system will automatically process neighboring information as well. This process has two consequences. First, studies have shown that heavy processing demands in the foveal part of the visual field reduce the extent of peripheral vision available (Erickson, 1964; Mackworth, 1965; Williams, 1982). This means that

peripheral vision will play less of a role in helping to guide foveal vision and search will be less guided, leading potentially to unnecessary fixations.

In addition, automatic processing of neighboring items slows the processing of the target item. Dobson (1980a, b) performed two studies which showed that information that is visually similar to the target information, even though it is known to be irrelevant to the task, impacts the speed and accuracy of performance, when it is located either vertically or horizontally with respect to the target information. A number of other studies (e.g. Eriksen & Eriksen, 1974; Harms & Bundesen, 1983) provided similar results. Eriksen and Hoffman (1972) argue that increased proximity of irrelevant information to target information requires more precise focusing, thus increasing the effort that must be expended by the visual system. The severity of the performance degradation appears to decrease as the distance between target and neighboring items increases (Kahneman & Chajczyk, 1983).

A study of label search on maps, by Noyes (1980), confirms these results. Irrelevant names, located either vertically or horizontally close to the target name, inhibited search performance. This was especially the case when the target name was horizontally located but close to a vertical name sharing the same first letter.

Place names in an open area, away from all other names. This is especially important when the names share the same first letter.

Interference can also occur between the label and its symbol. Phillips, Noyes, and Audley (1978) found that aligning the label either horizontally or vertically reduced the label's legibility. These results suggest that labels should be positioned slightly above or below, or to the left or right of, the symbol rather than along the same horizontal or vertical axis.

Position labels either slightly above or slightly below, or to the left or right of, their corresponding symbols so as to avoid placing the label along the same horizontal or vertical axis as its symbol.

Also, make sure that the amount of spacing is appropriate for the size of the label and symbol, including ascenders and descenders if a vertical orientation is used.

The amount of space between the symbol and the label depends upon the sizes of the type and symbol. The larger the type and symbol, the greater the distance that should be used between them.

6.4.5 Information Density Measures

Information bounding tools are intended to help reduce the density of information presented in a given location. Tullis (1983; also see Sarin & Ram, 1988) argues that two types of density must be considered: Overall density, which measures the percentage of character spaces used on a screen, and local density, the number of character spaces filled near each character. A variety of recommendations as to upper limits on overall information density have been suggested, rang-

ing from 15% to as high as 60% (Tullis, 1988). The value of these estimates is not clear. For example, in a study of screen density for instructional software, Morrison et al. (1989) found that subjects preferred high density screens because these screens provided the information necessary to understand the ideas being presented. It is very likely that a similar phenomenon will be found with IAP charts in that users may prefer to cope with one very dense page or screen, rather than multiple pages or screens. Consequently, the value of information density measures must be questioned, at least until they are able to take into account such factors as coherence of information presented.

Local density measures have suffered from their own set of problems. The study by Emurian and Seborg (1990), which demonstrated that search was faster for the denser tables contradicts what might be expected based upon local density measures. In fact, there is some evidence that local density may follow a U-shaped function (Tullis, 1983), but it remains for these functions to be clearly specified. Until a better understanding of user performance is obtained, density measures are likely to be of little use. It may be more effective to rely on such qualitative characteristics as grouping (the use of well-defined perceptual/conceptual groups) and layout complexity (the use of predictable visual structures) (Tullis, 1983).

6.5 SUMMARY

Chapter 5 provided guidance on how to ensure that each information element presented on a chart was sufficiently legible. In effect, the main objective was to emphasize the distinctiveness and discriminability of each element. The current chapter suggested methods for emphasizing *relationships* between elements, by means of such processes as similarity and grouping. Together, these chapters describe how to achieve the joint goals of element separability and interrelatedness that were initially described in Chapter 5.

Chapters 5 through 7 provide enough information to develop a complete IAP chart. Chapter 8 offers some tools for evaluating the overall effectiveness of the resulting chart. Once the individual elements have been designed and positioned, a final look at the chart will ensure that all of the elements work together to provide a coherent, integrated chart.

7. EVALUATING THE USE OF THE DESIGN TOOLS

7.1 OVERVIEW OF CHAPTER 7

Chapters 4 through 6 reviewed a variety of tools that may be of value in designing IAP charts. The review began by looking at tools for organizing the overall visual structure of the chart. Two chapters then followed that addressed the specifics of designing individual information elements, such as alphanumeric characters and symbols. This chapter, in a sense, completes the circle by returning to the chart as a whole. The tools described in this chapter are being treated in a slightly different way, however.

The principles that have been described in the previous chapters reflect a combination of research-based recommendations and good graphic design practice. Using these principles to their best advantage should result in a chart that is, at the very least, usable (and hopefully more than that). There are, however, obvious limitations as to how much flexibility is available to the chart designer in utilizing these recommendations. IAP charts are subject to a number of constraints, including limitations of space and requirements for accurate portrayal of geographic information.

This chapter reviews several important design objectives that pertain to all types of designed material. However, these objectives are treated here in a slightly different manner. Because the chart designer has so many objectives to consider, suggesting additional ones only serves to complicate matters. Consequently, the recommendations presented in this chapter are suggested as evaluative principles that should be used for final "tinkering" with the design rather than as initial design objectives.

These evaluative principles reflect requirements for the appearance of the chart as a whole, the need to present a chart with all of the information elements working together to provide a coherent structure reflective of the organizational logic of the chart. This need for unity between elements is complicated by the basic difficulty that, although each information element is designed individually, its impact is a function of how it influences, and is influenced by, all of the other information elements (Robinson, 1952). It is crucial that the elements work together as a systematic and integrated whole. Even if careful attention has been paid to how each information element has been embodied, there is still a need to look at the complete chart. The design tools in this chapter will aid in this process.

One general comment should be made about the tools described in this chapter. The guidance information presented to this point concerning the various design tools has been based upon a combination of experimental data and accepted design practice. In many respects, the guidance in this chapter is even more "squishy" than what has been presented to this point. The information in this chapter is abstract at best, difficult to describe, not yet experimentally evaluated, but

must be addressed because of its intuitive importance. Robinson (1952) describes the value of these principles when he writes that the overall visual structure of a chart "is a complicated combination of the application of the principles of overall shape, balance, proportion, and unity. These general principles, difficult to define and poorly understood scientifically, enter into every visual combination. ... Many of the principles have been derived by empirical [i.e. experiential] methods through many centuries of work by artists and designers. So far as is known the principles have not been tested in specific application except insofar as their persistence against competition may be considered testing. Until such time as logic and objective research concerning the relative efficiency of the various possibilities is undertaken, the cartographer can but rely on the experience and direction of the artist" (p. 70). Although written some 40 years ago, Robinson's observations remain true today as an important assessment of these abstract but important principles.

To aid in the final look at the overall appearance of a chart, three evaluative tools are described in this chapter:

- Visual balance
- Information density
- Figure/ground and contrast

7.2 VISUAL BALANCE

Visual balance refers to the layout of information elements and their contribution to the overall equilibrium of the chart. "Every layout requires stable equilibrium or balance. The masses must be so weighed against one another that they appear to have *settled* in the positions they occupy—to belong there in other words. No unit of design should convey to the eye of the reader the idea that it is struggling to go somewhere else in the layout, nor should the layout look as if it were tipping over" (De Lopatecki, cited by Robinson, 1952, p. 71). A well-balanced map helps the map reader to attend to the important parts of the map and does not encourage the eye to focus on any one part to the exclusion of other, equally important parts. An unbalanced map, in contrast, can cause the eye to focus repeatedly on one part, making it difficult for the eye to move flexibly through the chart.

Balance is achieved when elements are appropriately placed with respect to the visual center of the chart. Elements must be positioned so as to be visually symmetrical along the left-right and top-bottom axes. This symmetry is achieved by ensuring that the visual elements along each axis match in terms of their visual weight. The metaphor of a teeter-totter is typically used to explain the concept of balance (see Figure 7-1). If the total visual weight on one side of the page is greater than the other side, the chart will be unbalanced.

The visual focal point of a page is approximately 5% above its actual center. Around this visual center are placed the individual information elements of the chart. Although balance is an important objective of graphic design, there are no simple rules for achieving it. Visual weight is not a function of element size alone. Instead, it is influenced by a variety of factors, including an element's location, value, brilliance, and contrast (see Table 7-1). Because so many factors are

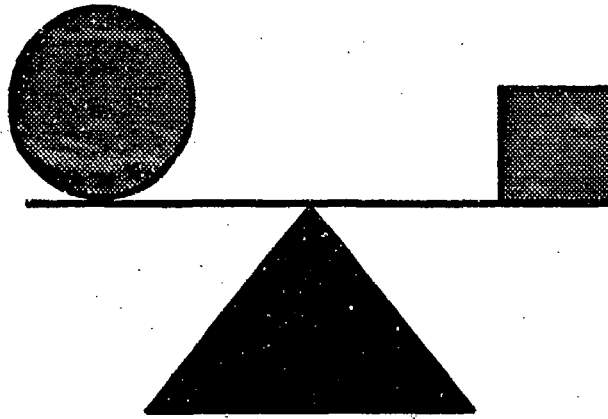


Figure 7-1. The "teeter-totter" metaphor of visual balance.

involved, balance must be achieved on the basis of the designer's own judgment, which is complicated by the constraints of limited chart space and the need for geographical accuracy

Blocks of text must also be assessed as to how they affect the overall balance of the chart. The amount of spacing between characters, words, and lines contributes to the overall "color" of the text (West, 1990). Increased spacing produces a lighter text color. Consequently, it is possible to use subtle variations in spacing to achieve the desired text "color" which will contribute to the overall balance of the chart.

The chart should be balanced along both the vertical and horizontal axes.

7.3 INFORMATION DENSITY

One of the biggest concerns of the chart designer is the problem of information density and the accompanying issue of clutter. Since the amount of information that must be presented on a chart is not under the designer's control, the only solution is to find ways of presenting that information in the most manageable way possible. Chapters 5 and 7 reviewed a number of methods for helping the chart user to visually organize the chart.

In a sense, information density and clutter are issues relating to the "horizontal" layout of the chart, the ability of the user to identify the various pieces that comprise the chart as a whole. This view is compatible with Castner and Eastman's (1985; also see Eastman, 1985a, b) approach to the issue of complexity. For them, complexity relates to the ability of the chart user to construct a "cognitive model" or image of the chart that adequately reflects the structure of the chart and its elements.

Much of the guidance information provided in Chapters 4 and 6 attempts to deal with the problem of information density and clutter. At this stage in the design process it remains for the

Effect of location:

- Elements near the center have less weight than those farther away from the center.
- Objects in the upper part are heavier than objects in the lower part.
- Objects on the right appear heavier than objects on the left.
- Isolated objects appear heavier than surrounded objects.
- A visually heavy shape near the fulcrum is balanced by a visually lighter but larger body farther from the balance point.

Effect of size:

- Large objects appear heavier than small.

Color and Brightness:

- Red objects appear heavier than blue objects.
- Bright objects appear heavier than dark objects.
- White objects appear heavier than black objects.
- Objects that attract the eye (due to amount of detail or uniqueness) appear heavier than non-attracting objects.

Shape:

- Regularly shaped objects appear heavier than irregularly shaped objects.
- Objects of compact shape appear heavier than non-compact objects.
- Squares are heavier than circles.

Table 7-1. Principles of balance (adapted from Arnheim, 1974).

chart designer to review the design and evaluate the extent to which the chart is laid out in accordance with the original organizational logic. In effect, this means checking that appropriate elements group with each other, and not with inappropriate elements, and that white space has been used throughout the chart to embody variations in the hierarchical structure to which the elements belong. Finally, it means checking the overall chart for areas that appear to be especially cluttered or "busy."

IAP charts use a variety of tools for visually structuring information elements into meaningful clusters or groups (see Figure 7-2). At the highest level, boxes are used as bounding tools, in combination with a consistent location, to define predictable sections of the chart. Within each section, grouping tools are used in accordance with the graphic format (topographical layout, graphic layout, tabular format, textual format) used. For the plan and airport sketch sections, symbols are used to group information elements of the same type (e.g. obstacles versus VORTACs). Pointing and "leading" are also used in order to direct the eye towards related information elements (the final approach and the various markers). Finally, the requirement for geographical accuracy serves to determine where landmark information elements are to be placed.

The tabular format in the profile and airport sketches demonstrates the use of lines to bound information elements. These bounding lines define both the limits of the table and the cells within the table. The hierarchical nature of the table supports a visual structure that enables appropriate grouping of related information elements within the table. To differentiate between the two sets of landing minimums presented within the table, size coding has been used, with the more commonly used information presented using the large type size.

Finally, a graphic layout is used to structure the profile view. Each critical segment is defined through the use of vertical dashed lines which also aid in relating navigation fixes to the appropriate segment.

The substantial amount of information presented on an IAP chart requires the strategic use of those tools which will support perceptual grouping of related information. In evaluating the success of a chart design, the clarity of the grouping procedures which have been used should be carefully evaluated.

Ensure that the chart adequately conveys grouping relationships that produce meaningful clusters of information on the chart. Also make sure that white spacing is used throughout the chart to appropriately specify hierarchical relationships. Finally, check for areas that are too cluttered.

7.4 FIGURE/GROUND AND CONTRAST

Figure/ground manipulation by means of contrast serves two uses in chart design. First, it can be used to ensure that important information, in effect, pops out from a more neutral background. In addition, variations in the "strength" of figure/ground relations, by means of variations in contrast, can be used to order information elements that belong to different visual layers but must be located close to each other on the chart (see Chapter 5).

During the final review of the chart design, both aspects of figure/ground must be assessed. First, it is important to ensure that all information elements possess sufficient contrast to be easily discriminated from the background and other information elements.

Ensure that all information elements possess sufficient contrast to support easy discrimination from background and neighboring elements.

Given that all information elements are sufficiently legible, the next step is to check that variations in contrast between elements (especially those located near, or on top of each other) reflect the organizational logic used to design the chart. Chapter 5 described the method of layering and how it can be used to specify variations in hierarchical level corresponding to the chart logic. If the layering approach has been used, its effectiveness in adequately representing hierarchical differences visually must be determined. It is especially important to make sure that symbols and letters are the most visually dominant elements on the chart (Dent, 1972).

Ensure that variations in contrast between elements are sufficient to be detectable and are accurate in reflecting hierarchical differences among those elements.

The designer should check that each information element has its own continuous contour that clearly differentiates it from the background and all other elements (Wood, 1968). If two elements share the same contour, figure/ground instability may occur. Also be sure that, if layers are superimposed, there are no unexpected masking effects due to similarity, proximity, continuity, or grouping across layers.

Check that every information element has its own continuous contour and that no masking due to similarity, continuity, or grouping has occurred across layers.

Finally, and perhaps most important of all, the designer should make sure that the various design tools are used consistently and not at cross-purposes with each other. Otherwise, visual contradictions can occur that might confuse the user.

Check that the design tools have been used consistently.

7.5 A FINAL WORD ON USING THE TOOL BOX

The concept of a tool box has been offered as a way of compensating for the lack of specific guidelines on how to design a perceptually usable IAP chart. Inherent in this approach is the objective of identifying the variety of tools that can be used and providing some guidance on how best to use them. It is then the task of the designer to take this information and determine how to apply it to a specific chart.

Although the goal of this Handbook is to provide enlightenment and suggestions for some potentially new ways of designing charts, it is also possible to come away with a sense of frustration at the complexity of the chart design process. There may be some reassurance in knowing that this frustration is shared by others. For example, the respected cartographer, George Jenks suggests a relationship between chart design and a woman called Pandora: "...I would remind you of the mythical woman, Pandora. When we started on this search we thought that pieces of the map reading puzzle might fall into place quite readily. Instead the ills, woes, and troubles of all of thematic cartography have been turned loose to haunt us. Simple dot maps no longer seem

simple. Ancillary information, often placed in the periphery of a map, seems to distract the reader and apparently distorts the message of the map. Symbolization practices such as the use of an infinite number of proportional circles instead of a classed set seem to waste the designer's and reader's time. The location of titles, legends, and map scales no longer seems to be just a matter of balance but becomes of major importance in directing the map reading task. These are but a few of the dogmas of thematic map design that seem to be threatened as we continue to explore the unknown areas of map communication" (Jenks, 1973, cited by Steinke, 1987, p. 57). What would appear to be simple grows in complexity as awareness of the number and importance of variables grows.

When coping with complex issues, it is not uncommon to assume that all of the problems and confusions will disappear with additional research. As Jenks' quote suggests, however, the solution is not that simple. Although research has provided us with glimpses as to how charts should be designed, the complaint can be made that we have not learned very much as a result of a good deal of time and effort. There are at least three reasons that explain why this is the case. First, the number of variables that must be tested, both alone and in combination, is enormous. This chapter began with the observation that each information element impacts, and is impacted by, every other information element. Consequently, small gains in understanding will come slowly.

In addition, the effects on performance of these variables is likely to be small and we may not have sufficiently sensitive tools for measuring their effect on performance. As a result, we may be unable to achieve an adequate view of how these variables impact chart use. However, even though their impact is small, this does not mean that they can be ignored. Each variable, alone, may make only a small difference but, together, their effect on performance could be substantial. Unfortunately, we don't know how.

These concerns are not constrained to chart design. Typographers (Macdonald-Ross & Waller, 1975) and instructional software user-interface designers (Grabinger, 1989) have expressed similar feelings. For example, Grabinger argues that screen design manipulations are relatively minor, as compared to other aspects of the instructional setting, yet researchers are surprised when large influences on performance are not found. His conclusion is metaphoric but appropriate: "We have broken the 4:00 minute mile. The improvements now come not in whole seconds, but in tenths of a second. We must design our research in such a way. We must look for the little things that make a difference in hopes that when we put a lot of little things together we will bump another tenth of a second off the clock" (p. 182). The same logic appears to be appropriate for chart research as well.

Also, it may be necessary to consider alternative ways of doing research. Traditionally, researchers look at the effects of one or a few variables on performance. Painstaking control of each variable, it is argued, allows greater understanding of the effect of that variable on performance. It may be useful, however, to complement this micro approach with a molar approach that involves developing alternative versions of a chart and evaluating them as a whole. Although this holistic approach will probably not contribute to the identification of specific guidelines for designing various types of information elements, it may provide a more efficient way of producing usable charts.

Finally, it is important to remember that chart reading is a cognitive task as well as a perceptual one. This Handbook has attempted to address the range of perceptual issues that influence chart reading. It has not, however, looked at the cognitive aspects. This is a gap that clearly needs to be addressed. Treating perceptual functioning as separate from cognitive functioning is a questionable activity in that there is hard no boundary that clearly separates the two activities.

Take, for example, the process of visual search. A large proportion of the words written in this Handbook attempt to describe how IAP charts can be designed to better support the search process. Unfortunately, visual search is heavily influenced by the chart user's expectations and familiarity with charts, as well as his/her experience with the geographical location represented in the chart. It is all well and good to talk about how to support perceptual grouping and discriminability of symbols but to say something truly meaningful means considering how the user makes sense of the spatial arrangement of symbols and the locational meaning implied in them (Guelke, 1979). Petchenik (1977) shares the concern that cognitive aspects of chart use must be considered: "While cartographic researchers have concentrated on the perception of individual map symbols or on limited comparisons among symbols, the problem of map reading extends far beyond such concerns. But the notion of map reading itself has not yet received as much attention as it should have. The real problem is this: How does a map user develop internal, personal knowledge of relations among things in space on the basis of viewing a sheet of paper covered with ink marks? How, in common language, does one read a map?" (p. 118).

Clearly, it is important to address the "cognitive" issues of chart use, such as how users make sense of charts, how they match chart information to the information they see outside the cockpit window, and how the navigation process works. Even a little understanding of how the user cognitively utilizes a chart is likely to have a substantial impact on chart design, including the so-called perceptual aspects.

It is hoped that the design information offered in this Handbook will prove to be of value in improving chart design, even though it certainly will not be the last word on how to design IAP charts. But given the limitations in our understanding of the chart user, one final recommendation should always be kept in mind:

Each chart design ultimately should be experimentally tested to determine its real effectiveness in supporting perceptual interaction with it by the user.

8. THE DESIGN PRINCIPLES

2. DISPLAY IMAGE QUALITY

2.5 Spatial Vision

2.5.1 RESOLUTION (PAPER, CRT, LCD)

Resolution on CRT or LCD screens should be as high as achievable for electronic media up to the standard used for paper. For the unaided observer, the critical test is whether the sizes of alphanumeric characters and symbols that are actually used is sufficient to compensate for the lower resolution level available for the selected displays. For paper, an effective resolution of 300 dpi (print quality of 600 dpi) has proven to be acceptable.

2.5.2 LUMINANCE (CRT, LCD)

Manual controls, either in conjunction with or independent of automatic controls, should be made available to the user to vary mean screen luminance. The appropriate screen luminance range will be dependent upon the contrast ratio and size of displayed symbology, hence a minimum value cannot be specified. However, a range of 0.1 to 200 fL has been suggested. For the unaided observer, the range of available luminance levels should be sufficient to handle the range of ambient lighting conditions likely to be found in the cockpit environment. Sufficient luminance and/or chromatic difference should always be available to support discrimination between all symbols, characters, and backgrounds.

2.5.3 LUMINANCE CONTRAST AND CONTRAST RATIO (PAPER, CRT, LCD)

For CRTs and LCDs, a minimum luminance contrast ratio of 20:1 for direct viewing and 10:1 for all other viewing situations is desirable. For segmented displays, the contrast ratio should be 2:1 for activated segments and 1.15:1 for unactivated segments. For the unaided observer, the display should be evaluated under a range of cockpit environment conditions to ensure that sufficient luminance contrast is always possible.

For paper displays, IAP charts should be printed with sufficient contrast between the characters and their background that they are easily read in all viewing situations.

2.5.4 LUMINANCE UNIFORMITY (CRT, LCD)

For the unaided observer, non-uniformities in brightness or color on CRT or LCD displays shall not be present. When varying the luminance of the display from minimum to maximum, the relative luminance of all characters, symbols, and backgrounds should be visually constant. Employing photometric techniques, a large area non-uniformity of less than 20% is acceptable. For luminance variations within half a degree of arc, 50% or less is acceptable.

2.5.5 CONTRAST DIRECTION/CONTRAST POLARITY (PAPER, CRT, LCD)

For CRT and LCD formats, positive polarity is probably preferred because of the unique information format requirements of IAP charts.

Contrast direction, on paper, should be dark symbols on a light background.

2.5.6 CONVERGENCE AND FOCUS (CRT)

For the unaided observer, lines, symbols, and characters should have no tails, squiggles, skews, gaps or bright spots. Line color should be obvious. Employing photometric measurements, misconvergence should not be greater than 0.7 milliradians.

2.5.7 SYMBOL ALIGNMENT (CRT, LCD)

To the unaided observer of a CRT or LCD, symbols which should be aligned either horizontally or vertically should appear so aligned. Employing photometric techniques, symbol alignment should be within 0.2 inches.

2.5.8 DEFECTS AND LINE FAILURES (CRT)

Any defects in the display should not be distracting or cause information misreading. Row or column failures should be improbable occurrences.

2.5.9 ANTI-ALIASING AND SHADES OF GRAY (CRT, LCD)

Lines and characters presented on CRTs or LCDs should appear smoothly written and contain no unwanted jagged edges. Special attention should be paid to angled lines drawn on LCDs, which are the most difficult to anti-alias.

A minimum of 15 gray levels is likely to be required for near-term IAP chart electronic displays.

2.5.9 VIEWING ANGLE (CRT, LCD)

Current aerospace recommendations require a viewing angle of 53 degrees in the left and right direction, 35 degrees above, and 0 degrees below a plane perpendicular to the screen face. However, display location and additional crew member viewing may require different specifications. Special attention should be paid to the viewing angle characteristics of any proposed LCD IAP chart.

2.6 Temporal Vision

2.6.1 FLICKER AND REFRESH RATE (CRT, LCD)

For the unaided observer of a CRT or LCD, there should be no undesired rapid temporal variation in display luminance for a symbol or display field. For CRTs, a refresh rate of 50 - 60 Hz is generally acceptable. For LCDs, a frame rate of 30 Hz may be acceptable.

2.6.2 JITTER (CRT, LCD)

For the unaided observer, a static CRT or LCD display should contain no discernible jitter. Employing photometric techniques, image jitter should be within 0.3 milliradians peak-to-peak.

2.7 CHROMATIC VISION (CRT, LCD)

Any use of color in electronic IAP charts should be adequately tested in flight situations with a representative sample of pilots. As a guideline for the design of such devices, ARP 4032 should be consulted.

There should be sufficient chromaticity uniformity to ensure adequate interpretation of information.

4. ORIENTING WITHIN THE IAP CHART

4.2 The Visual Structure of an IAP Chart

Before beginning the design process, prepare a hierarchical organization that specifies the categories of information that will be used and the elements that belong to each category. Define the categories on the basis of the types of relationships to be emphasized in the design.

4.3 Specifying Parts

4.3.1 DISTINCTIVE VISUAL APPEARANCE

Preserve the unique appearance of each major section of the chart.

4.3.2 STANDARD LOCATION

Whenever possible, design the chart to have standard locations for categories of information and, when possible, for individual information elements.

4.3.3 METHODS FOR DEFINING BOUNDARIES

Use a bounding tool to define parts of a chart. Boxes provide the strongest method for visually bounding a space. Lines are a more subtle method that is especially useful for defining lower-level boundaries such as between elements in a table. To avoid further cluttering a chart that already possesses a large number of line elements, white space can be used.

4.4 Specifying Relationships

4.4.1 SAME HIERARCHICAL LEVEL, SAME LOCATION

Proximity provides a strong visual cue for shared category membership.

Tools such as standard location and boundaries can be used to specify related information if the information elements that possess the shared property can be physically located near each other.

4.4.2 SAME HIERARCHICAL LEVEL, DIFFERENT LOCATION

Conceptual grouping of information elements can be encouraged by assigning a common visual property (color, texture, shape, size) to members of that group.

The method of "pointing" offers a useful tool for guiding the eye from one related item to another while avoiding the clutter that can occur from the use of lines and other direct connecting methods. If pointing is used, make sure that the path specified by the originating element will move the eye to the intended target element. Also, make sure that unintended pointing is avoided.

"Leading" the eye from one information element to another by means of lines or arrows provides the strongest means for relating similar elements. It should be used sparingly, however, to avoid clutter.

4.4.3 DIFFERENT LEVELS, SAME LOCATION

Use variations in the sharpness of edges to define multiple information element layers.

Variation in brightness contrast is a useful tool for differentiating between items from different layers. For monochromatic charts, information elements on the higher levels should be darker than elements on the lower layers. If color is used, brighter colors should be used for the higher layers.

If multiple patterns that are equally bright but vary in coarseness of texture and size of dot are superimposed on each other, the coarser texture should be positioned on the highest layer.

The amount of detail provided on a symbol can be used to vary contrast. Detailed symbols tend to stand out as figure against less detailed symbols.

Varying line weight is an effective tool for signifying variations in layers if care is taken to ensure that the lightest weight provides sufficient visual contrast to be legible.

Variations in line character can be useful for differentiating element layers using lines used to construct their own figures.

Use discretion in the number of layers, texture patterns, line weights, and line characters that are used. Too many may be worse than too few.

Interposition provides a strong cue that one element is located in a layer that is different from another element. Care should be taken in using this tool to ensure that the partially hidden element is still recognizable and the shape of its hidden parts predictable.

4.4.4 DIFFERENT LEVELS, DIFFERENT LOCATIONS

Variations in relative size can be made to ensure that important elements are more likely to be seen. This should not be done at the expense of decreasing the legibility of less important items.

5. SEARCH AND LEGIBILITY

5.3 Font Characteristic Tools

5.3.1 TYPEFACE

Use a familiar typeface that is clean and simple, avoiding unnecessary flourishes. Use of sans serif typefaces may be more appropriate than serif typefaces due to potentially poor lighting conditions in the cockpit and to avoid problems in printing or displaying typefaces with hairline stroke widths.

5.3.2 FONT SIZE

Increasing the size of type improves search performance for critical information at least up to the level of 12 point type or approximately 20 minutes of visual angle. It is not yet known whether increasing type size beyond this level will improve performance but there is some evidence to suggest that this is the smallest size that should be used for changing but non-critical information. Critical information should probably be presented using a larger type size, such as 14 point on paper or 30 minutes for electronic displays.

5.3.3 TYPEFACE SPACE ECONOMY

When choosing between typefaces, select the typeface that allows more characters per line.

5.3.4 TYPE PROPORTIONS

The standard stroke-to-height ratio for typefaces used with paper is 1:10.

For electronic media, stroke widths of between 1:6 and 1:8 are recommended.

Avoid using a typeface that has large variations in stroke width.

The type weight used should support contrast between type and its background that is sufficient to allow accurate and efficient recognition of the information.

When choosing between typefaces, use the typeface with the higher x-height.

5.3.5 INDIVIDUAL CHARACTER CONFUSIONS

Ensure that all typeface characters are easily discriminable.

Avoid using a typeface that includes unusual letter shapes.

5.3.6 TYPE CASE

Available research data suggests that upper/lowercase letter combinations are read more quickly and support more efficient search for names on a map than upper-case letters used without lower-case letters.

5.3.7 INTER-CHARACTER SPACING

Spacing between characters within a word should be at least 10 to 15% but should be assessed visually to ensure that the spacing looks consistent for all combinations of word characters.

Use one character space to separate words.

5.3.8 LEADING

The spacing between bottom of descenders on one line and the top of ascenders on the next line should be approximately 15% of character height. The spacing should be visually assessed to ensure that it looks consistent.

5.3.9 ROTATED TYPE

Whenever possible, avoid presenting text in a non-horizontal orientation.

5.3.10 TYPE/BACKGROUND CONTRAST

Discriminability of alphanumeric symbols which must be located on a patterned background may be improved by presenting that information in a box which has a non-patterned background.

5.4 Symbol Characteristics Tools

5.4.1 SYMBOL SHAPE

Simple, familiar symbol shapes should be used whenever possible.

Ensure that each geometric shape is maximally distinctive by utilizing that shape's defining dimension.

Symbols should be designed to have distinctive global shapes.

Use a strong outline contour to define each symbol in accordance with its relative position within the visual structure of the chart.

Avoid using detailed local structure to define symbols. Instead, symbols should be discriminable on the basis of their global shape.

Use filled symbols rather than open symbols.

Ensure that each symbol stands out as a strong figure against all background patterns and elements.

5.4.2 SYMBOL SIZE

When making decisions about symbol size, consider all of the factors that impact symbol effectiveness, including legibility requirements, role and position of each symbol within the visual structure of the chart, apparent visual size, and space constraints.

5.4.3 SYMBOLS AND COLOR

Color, used solely as a means of adding realism or attractiveness to symbols, should be avoided.

5.4.4 ACHIEVING SYMBOL LEGIBILITY

If a symbol that has been used on paper charts is to be transferred to the electronic medium, be sure to determine if sufficient resolution is available to support the symbol. Otherwise the symbol may have to be modified to take into account the reduced resolution of the electronic display.

6. SEARCH AND PERIPHERAL VISION

6.2 Information Highlighting Tools

6.2.1 HIGHLIGHTING THROUGH BRIGHTNESS

Under good viewing conditions, highlighting through brightness is both effective and not annoying to the user. However, its effectiveness is reduced under high ambient illumination levels, on low contrast displays, and when the highlighted elements are small.

6.2.2 HIGHLIGHTING THROUGH BOLDING

Bolding of important names does not appear to improve performance and should be avoided as it may contribute to chart clutter.

6.2.3 HIGHLIGHTING THROUGH REVERSE VIDEO

Reverse video is an effective means of attracting the user's attention but it can reduce the legibility of highlighted information. In addition, it may distract the eye when the target information is not highlighted.

6.2.4 HIGHLIGHTING THROUGH BLINKING

Highlighting through blinking should only be used to inform the user of a critical situation. For this reason, its use on IAP charts is probably not appropriate.

6.2.5 HIGHLIGHTING THROUGH UNDERLINING

Underlining is not a strong attention-getter but it may have limited utility as a way of highlighting a small amount of information that is located with other information in a restricted space.

6.2.6 HIGHLIGHTING THROUGH BOXING

The relative benefits of highlighting through boxing are not clear. If boxing is used, be sure to use a box that is sufficiently large to support legibility of the information located within the box.

6.2.7 LIMITATIONS OF HIGHLIGHTING

Although highlighting can improve search efficiency for highlighted information, it may reduce efficiency for non-highlighted information. When deciding whether to use highlighting, strong consideration must be given to possible negative consequences that can arise through the use of highlighting.

If the decision is made to use highlighting, it should be used conservatively and appropriately, in keeping with the information needs of the user.

6.3 Information Coding Tools

6.3.1 COLOR CODING

Use color only if the display segmentation required by each task corresponds to the segmentation encouraged by the application of color.

Color coding, used redundantly with another form of coding such as shape, improves performance when the task requires search. Its use may improve the performance of users searching for information elements located in the plan section of the chart.

Use of colors that are easily distinguishable can support nearly parallel processing of color.

The improvement in performance due to the use of color coding decreases as the number of items that share the same, target color increases. Performance is less affected by variations in the number of items with non-target colors.

Visual search times increase as the number of colors used increases.

Restrict the number of colors used to less than eight or nine if the user must remember what the colors mean.

If the color is known in advance, performance will improve with the use of color. If the color is not known, performance is worse than with no color.

If search for non-colored items is required on a display where color is used, performance will be reduced.

Color coding of a single item reduces the time needed to locate that item.

Color coding can improve search times for names presented on maps if the user knows the color to look for.

Color coding may not be effective and can degrade performance if the task requires identification but no search.

Users like color and it may improve their performance in dual-task situations.

Color is an effective tool for supporting map users' abilities to judge relative heights and visualize the terrain. Monochromatic coding methods, however, may be just as effective.

A better understanding of the IAP chart user's needs should be obtained before choosing a method for embodying land surface height information.

If color is used, take into consideration these problems of color use when selecting colors and always use color redundantly with other coding schemes, such as shape.

When selecting colors, take into account the range of ambient illumination levels that will occur, the limitations of the system used to generate the colors, the sizes of the areas to which the colors will be applied, and unexpected effects due to presenting combinations of colors.

Use a color coding scheme that is consistent with other displays in the cockpit.

6.3.3 SHAPE CODING

Shape is a necessary coding method in the IAP chart situation and should always be used redundantly if other coding methods are employed.

6.4 Information Bounding Tools

6.4.1 REDUCING THE AMOUNT OF SPACE TO BE SEARCHED

Providing an organizational structure to help the chart user orient, combined with control over the density of symbols in any one part of the chart, will contribute to efficient visual search.

6.4.2 INFORMATION BOUNDING AND THE USE OF COLUMNS

Search performance appears to be faster for items arranged in columns rather than rows.

Column sizes of five degrees or less appear to support the most effective search.

Graphic boundaries don't appear to affect performance either positively or negatively. It may be premature to discard the graphic lines, however.

It would appear that search for information stored in tables is not aided by increasing the spacing between table elements.

6.4.3 REDUCING INTER-ITEM INTERFERENCE

Place names in an open area, away from all other names. This is especially important when the names share the same first letter.

Position labels either slightly above or slightly below, or to the left or right of, their corresponding symbols so as to avoid placing the label along the same horizontal or vertical axis as its symbol.

The amount of space between the symbol and the label depends upon the sizes of the type and symbol. The larger the type and symbol, the greater the distance that should be used between them.

6.4.5 INFORMATION DENSITY MEASURES

7. EVALUATING THE USE OF THE DESIGN TOOLS

7.2 Visual Balance

The chart should be balanced along both the vertical and horizontal axes.

7.3 Information Density

Ensure that the chart adequately conveys grouping relationships that produce meaningful clusters of information on the chart. Also make sure that white spacing is used throughout the chart to appropriately specify hierarchical relationships. Finally, check for areas that are too cluttered.

7.4 Figure/Ground and Contrast

Ensure that all information elements possess sufficient contrast to support easy discrimination from background and neighboring elements.

Ensure that variations in contrast between elements are sufficient to be detectable and are accurate in reflecting hierarchical differences among those elements.

Check that every information element has its own continuous contour and that no masking due to similarity, continuity, or grouping has occurred across layers.

Check that the design tools have been used consistently.

7.5 A Final Word on Using the Tool Box

Each chart design ultimately should be experimentally tested to determine its real effectiveness in supporting perceptual interaction with it by the user.

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